TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

MECHANICAL ENGINEERS.

VOL. XIX.

XXXVITH MEETING, NEW YORK, 1897.
XXXVIITH MEETING, NIAGARA FALLS, N. Y., 1898.

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1898.

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OFFICERS

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

1897–1898,

FORMING THE STATUTORY COUNCIL.

PRESIDENT.

CHARLES WALLACE HUNT........New York City.

VICE-PRESIDENTS.

E. S. CRAMP........Philadelphia, Pa.
S. T. WELLMAN........Cleveland, Ohio.
W. F. DURFEE........New York City.
Terms expire at Annual Meeting of 1898.

JOHN C. KAFER........New York City.
CHAS. M. JARVIS........Berlin, Conn.
WALTER S. RUSSEL........Detroit, Mich.
Terms expire at Annual Meeting of 1899.

MANAGERS.

NORMAN C. STILES........Watertown, N. Y.
E. D. MEIER........St. Louis, Mo.
GEO. W. DICKIE........San Francisco, Cal.
Terms expire at Annual Meeting of 1898.

H. S. HAINES........In Europe.
GUS. C. HENNING........New York City.
A. WELLS ROBINSON........So. Milwaukee, Wis.
Terms expire at Annual Meeting of 1899.

JAS. B. STANWOOD........Cincinnati, Ohio.
HENRY H. SUPLEE........New York City.
GEO. RICHMOND........New York City.
Terms expire at Annual Meeting of 1900.

TREASURER.

WM. H. WILEY........No. 53 East 10th St., New York City.

SECRETARY.

PROF. F. R. HUTTON........No. 12 West 31st St., New York City.

NOTE.

THE considerable bulk of the annual volume of *Transactions* has induced the Publication Committee to direct that the full list of members of the Society should be omitted from the preliminary matter therein. The list which would have been published in this volume is that which was corrected up to July, 1898, and which was issued at that time in pamphlet form as a second edition of the Nineteenth Catalogue. The following summary records the number of members in each grade :

Honorary Members	15
Members	1,394
Associate Members	124
Junior Members	343
Total Membership	1,876
Life Members *	73

* These Life Members are included in the total membership above, in the class to which they belong.

PAST OFFICERS.

(EXECUTIVE.)

PRESIDENTS.

R. H. THURSTON (April 7th, 1880—Nov. 3d, 1882), **E. D. LEAVITT, JR.** (Nov. 3d, 1882—Nov. 3d, 1883), **JOHN E. SWEET** (Nov. 3d, 1883—Nov. 7th, 1884), **J. F. HOLLOWAY** * (Nov. 7th, 1884—Nov. 13th, 1885), **COLEMAN SELLERS** (Nov. 13th, 1885—Dec. 2d, 1886), **GEO. H. BABCOCK** † (Dec. 2d, 1886—Dec. 1st, 1887), **HORACE SEE** (Dec. 1st, 1887—Oct. 18th, 1888), **HENRY R. TOWNE** (Oct. 18th, 1888—Nov. 22d, 1889), **OBERLIN SMITH** (Nov. 22d, 1889—Nov. 14th, 1890), **ROBT. W. HUNT** (Nov. 14th, 1890—Nov. 20th, 1891), **CHAS. H. LORING** (Nov. 20th, 1891—Nov. 29th, 1892), **ECKLEY B. COXE** ‡ (Nov. 29th, 1892—Dec. 4th, 1894), **E. F. C. DAVIS** § (Dec. 4th, 1894—Aug. 6th, 1895), **CHAS. E. BILLINGS** ‖ (Aug. 6th, 1895—Dec. 3d, 1895), **JOHN FRITZ** (Dec. 3d, 1895—Dec. 5th, 1896), **WORCESTER R. WARNER** (Dec. 5th, 1896—Dec. 3d, 1897).

TREASURERS AND SECRETARIES.

Treasurers.—**LYCURGUS B. MOORE** (April 7th, 1880—Dec. 2d, 1881), **CHAS. W. COPELAND** ¶ (Dec. 2d, 1881—Nov. 7th, 1884).

Secretaries.—**LYCURGUS B. MOORE** (*Acting*, April 7th, 1880—Nov. 4th, 1880), **THOS. WHITESIDE RAE** ** (Nov. 4th, 1880—March 1st, 1883).

MEMBERS OF PREVIOUS COUNCILS.

VICE-PRESIDENTS.

HENRY R. WORTHINGTON,†† **COLEMAN SELLERS**, **ECKLEY B. COXE**,‡ **Q. A. GILLMORE**, **WM. H. SHOCK**, **ALEX. L. HOLLEY**,‡‡ **F. A. PRATT**, **W. P. TROWBRIDGE**,§§ **E. D. LEAVITT, JR.**, **CHAS. E. EMERY**, **JOHN FRITZ**, **HENRY MORTON**, **WM. METCALF**, **S. B. WHITING**, **A. B. COUCH**, **W. R. ECKHART**, **J. V. MERRICK**, **CHARLES W. COPELAND**,¶ **OLIN LANDRETH**, **HENRY R. TOWNE**, **C. H. LORING**, **HORACE SEE**, **ALLAN STIRLING**, **JOS. MORGAN, JR.**, **C. T. PORTER**, **HORACE S. SMITH**, **W. S. G. BAKER**, **H. G. MORRIS**, **C. J. H. WOODBURY**, **THOS. J. BORDEN**, **WM. KENT**, **CHAS. B. RICHARDS**, **JOEL SHARP**, **GEO. W. WEEKS**, **DE VOLSON WOOD**, **S. W. BALDWIN**, **JOHN F. PANKHURST**, **ALEXANDER GORDON**, **GEO. I. ALDEN**, **E. F. C. DAVIS**, **IRVING M. SCOTT**, **C. W. HUNT**, **THOS. R. PICKERING**, **EDWIN REYNOLDS**, **C. E. BILLINGS**, **PERCIVAL ROBERTS, JR.**, **H. J. SMALL**, **F. H. BALL**, **JESSE M. SMITH**, **M. L. HOLMAN**, **GEO. W. MELVILLE**, **CHAS. H. MANNING**, and **FRANCIS W. DEAN**.

MANAGERS.

W. P. TROWBRIDGE, §§ **T. N. ELY**, **J. C. HOADLEY**, ‖‖ **WASHINGTON JONES**, **WM. B. COGSWELL**, **F. A. PRATT**, **CHAS. B. RICHARDS**, **S. B. WHITING**, **J. F. HOLLOWAY**, **GEO. W. FISHER**, **ALLAN STIRLING**, **GEO. H. BABCOCK**, **S. W. ROBINSON**, **JNO. E. SWEET**, **R. W. HUNT**, **CHAS. T. PORTER**, **C. J. H. WOODBURY**, **W. F. DURFEE**, **OBERLIN SMITH**, **C. C. WORTHINGTON**, **WM. LEE CHURCH**, **WM. HEWITT**, **C. H. MORGAN**, **H. A. HILL**, **WM. KENT**, **S. T. WELLMAN**, **F. G. COGGIN**, **J. T. HAWKINS**, **T. R. MORGAN, SR.**, **S. W. BALDWIN**, **FRED'K GRINNELL**, **MORRIS SELLERS**, **FRANK H. BALL**, **GEO. M. BOND**, **WM. FORSYTH**, **JAS. E. DENTON**, **CARLETON W. NASON**, **H. H. WESTINGHOUSE**, **ANDREW FLETCHER**, **WORCESTER R. WARNER**, **COLEMAN SELLERS, JR.**, **JAS. M. DODGE**, **ROBT. FORSYTH**, **JESSE M. SMITH**, **CHAS. H. MANNING**, **C. W. PUSEY**, **JOHN THOMSON**, **JOHN B. HERRESHOFF**, **L. B. MILLER**, **W. S. RUSSEL**, **JOHN C. KAFER**, **CHAS. A. BAUER**, and **ARTHUR C. WALWORTH**.

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* Died, Sept. 1, 1896.
§ Died, Aug. 6, 1895.
** Died, May 27, 1893.
§§ Died, Aug. 12, 1892.
† Died, Dec. 16, 1893.
‖ Unexpired term of Mr. Davis.
†† Died, Dec. 17, 1880.
‖‖ Died, Oct. 21, 1886.
‡ Died, May 13, 1895.
¶ Died, Feb. 7, 1895.
‡‡ Died, Jan. 29, 1882.

HONORARY COUNCILLORS.

Past Presidents of the Society.

R. H. Thurston	1880—1882	Ithaca, N. Y.
E. D. Leavitt	1882—1883	Cambridgeport, Mass.
John E. Sweet	1883—1884	Syracuse, N. Y.
Coleman Sellers	1885—1886	Philadelphia, Pa.
Horace See	1887—1888	New York City.
Henry R. Towne	1888—1889	Stamford, Conn.
Oberlin Smith	1889—1890	Bridgeton, N. J.
Robert W. Hunt	1890—1891	Chicago, Ill.
Charles H. Loring	1891—1892	Brooklyn, N. Y.
Charles E. Billings*	1895	Hartford, Conn.
John Fritz	1895—1896	Bethlehem, Pa.
Worcester R. Warner	1896—1897	Cleveland, Ohio.

[Note.—The former Presidents of the Society are members of the Council for life or during their retention of active membership in the Society.]

* Unexpired term of E. F. C. Davis.

RULES OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

ART. 1. The objects of the AMERICAN SOCIETY OF MECHANICAL ENGINEERS are to promote the Arts and Sciences connected with Engineering and Mechanical Construction, by means of meetings for social intercourse and the reading and discussion of professional papers, and to circulate, by means of publication among its members, the information thus obtained.

ART. 2. All persons connected with engineering may be eligible for admission into the Society.

ART. 3. The Society shall consist of Honorary Members, Members, Associates, and Juniors.

ART. 4. Honorary Members, not exceeding twenty-five in number, may be elected. They must be persons of acknowledged professional eminence.

ART. 5. To be eligible as a Member, the candidate must be not less than thirty years of age, and must have been so connected with engineering as to be competent as a designer or as a constructor, or to take responsible charge of work in his department, or he must have served as a teacher of engineering for more than five years.

NOTE.—The Rules of the Society, adopted in 1880, were in force until 1884, when they received general revision by a careful committee, whose report, distributed by letter ballot, was adopted November 5, 1884. In December, 1894, a similar extensive revision was made under direction of the Council, and the present rules are those of 1894. They include the amendments made in 1889, 1891, and 1893, which were the only changes since the revision of 1884.

ART. 6. To be eligible as an Associate the candidate must be not less than twenty-six years of age, and must have the other qualifications of a member; or he shall have been so connected with engineering as to be competent to take charge of work, and to coöperate with engineers.

ART. 7. To be eligible as a Junior, the candidate must have had such engineering experience as will enable him to fill a responsible position, or he must be a graduate of an engineering school.

ART. 8. All Honorary Members, Members, and Associates shall be equally entitled to the privileges of membership. Juniors shall not be entitled to vote, nor to be officers of the Society.

ART. 9. Nominees for Honorary Membership must be proposed by at least five Members who are not officers of the Society. References shall not be required of a nominee for Honorary Membership, but the grounds upon which the application is made must be fully set forth in writing and signed by the proposers.

ART. 10. A candidate for admission to the Society, as a Member or as an Associate, must make an application on a form to be prepared by the Council, which shall contain a written statement giving a complete account of his engineering experience and an agreement that he will, if elected, conform to the laws, rules, and requirements of the Society. He must refer to at least five Members or Associates to whom he is personally known. A candidate for admission to the Society as a Junior must make an application on the same form, and refer to not less than three Members or Associates to whom he is personally known.

ART. 11. The referees for each candidate for admission to the Society shall be requested to make a confidential communication on a form to be prepared by the Council, setting forth in detail such information, personally known by the referee, as shall enable the Council to arrive at a proper estimate of the eligibility of the candidate for admission to the Society. Such confidential communications shall be destroyed by the Secretary as soon as the vote has been officially declared.

ART. 12. All applications for membership must be presented to the Council, and this body shall consider each application, assigning to each, with the applicant's consent, the grade in

the Society to which, in its opinion, his qualifications entitle him. The names of those candidates recommended for election by the Society shall be immediately printed on a ballot, and the ballot mailed at once by the Secretary to each voting member of the Society. Persons desiring to change their grade of membership from junior to associate or from associate to member shall make an application in the same manner and on the same form as that required for a new applicant.

ART. 13. A member entitled to vote may leave the name of any candidate on the ballot untouched to vote in favor of the admission of the candidate to the Society, or he may erase the name to vote against it. He shall enclose the ballot so approved by him in a sealed blank envelope, and enclose this envelope in a second envelope, on which he shall write his name, and mail the same to the Secretary of the Society. A ballot without such endorsement shall be rejected as defective. The rejection of a candidate by seven voters shall defeat his election.

ART. 14. The aforesaid envelopes containing the ballots shall be opened by the Council, at any meeting thereof, and the names of those elected shall be announced in the next meeting of the Society. The names of applicants not elected shall not be announced, nor recorded in the proceedings.

ART. 15. Endorsers of any applicant not elected may, within three months after such failure to be elected, lay before the Council written evidence that an error was then made. The Council may then, by a three-fourths vote, order another similar ballot by the Society, in which case thirteen negative votes shall be required to defeat the candidate.

ART. 16. Honorary members shall be elected by the unanimous vote of the Council, through a letter ballot, not less than sixty days subsequent to the proposal, a notice of which proposed election shall have been mailed at once by the Secretary to each member of the Council.

ART. 17. Each person elected, excepting honorary members, must subscribe to the Rules of the Society, and pay the initiation fee before he can receive a certificate entitling him to the rights and privileges of the Society, and to wear the emblem appropriate to his grade. If this payment is not made within six months of the election, the same shall be void, unless the time is extended by the Council. The emblems of each grade of membership shall be worn by those only who belong to that grade.

ART. 18. The initiation fee of a member or an associate shall be twenty-five dollars, and the annual dues shall be fifteen dollars, payable in advance. The initiation fee of a junior shall be fifteen dollars, and his annual dues ten dollars, payable in advance. A junior being promoted to any other grade of membership shall pay an additional initiation fee of ten dollars. Any member or associate may become a Life Member in the same grade, by the payment of two hundred dollars at one time, and shall not be liable thereafter to annual dues.

The Council shall have the power, for special reasons, by unanimous vote, through a letter ballot, to admit to life membership, without the payment of the sum above named, such person as for a long term of years has been a member or an associate, when such a procedure would in its judgment be for the best interests of the Society; provided that notice of such action shall have been given at a previous meeting of the Council.

ART. 19. Any member of the Society in arrears may, at the discretion of the Council, be deprived of the publications of the Society, or, when in arrears for one year, he may be stricken from the list of members. Such person may be restored to the privileges of membership by the Council on payment of all arrears.

ART. 20. The affairs of the Society shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers, and a Treasurer, who shall also be the Trustees of the Society.

All past (ex) Presidents of the Society, while they retain their membership therein, shall be known as Honorary Councillors, and shall be entitled to receive notices of all meetings of the Council and may take part in any of its deliberations; they shall be entitled to vote upon all questions except such as affect the legal rights or obligations of the Society or its members.

ART. 21. The members of the Council shall be elected from among the members and associates of the Society at the annual meetings, and shall hold office as follows:

The President and the Treasurer for one year; and no person shall be eligible for immediate re-election as President who shall have held that office for two consecutive years; the Vice-Presidents for two years, and the Managers for three years; and no Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected.

ART. 22. A Secretary, who shall be a member of the Society,

shall be appointed for one year by a majority of the members of the Council at its first meeting after the annual election, or as soon thereafter as the votes of a majority of the members of the Council can be secured for a candidate. The Secretary may be removed by a vote of twelve members of the Council, at any time after one month's notice has been given him by a majority of its members to show cause why he should not be removed, and he has been heard to that effect. The Secretary may take part in any of the deliberations of the Council, but shall not have a vote therein. His salary shall be fixed for the time he is appointed by a majority vote of the Council.

ART. 23. At each annual meeting, a President, three Vice-Presidents, three Managers, and a Treasurer shall be elected, and the term of office of each shall continue until the end of the meeting at which their successors are elected.

ART. 24. The duties of all officers shall be such as usually pertain to their offices or may be delegated to them by the Council or by the Society. The Council may, in its discretion, require bonds to be given by the Treasurer.

ART. 25. The Council may, by vote of a majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings, or to perform the duties of his office. All such vacancies and those occurring by death or resignation shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *provided* that the said appointment shall not render him ineligible at the next annual meeting.

ART. 26. Five members of the Council shall constitute a quorum. Members of a Council absent from a meeting may vote by letter upon subjects stated in the call for the meeting, said vote to be deposited with the Secretary.

ART. 27. The President on assuming office shall appoint a Finance Committee and a Publication Committee and a Library Committee of five members each. The appointment of two members of each Committee shall expire at the end of each year. The Secretary shall, *ex officio*, be a member of all three committees.

ART. 28. The Finance Committee shall have power to order all ordinary or current expenditures, and shall audit all bills therefor.

No bill shall be paid except upon their audit. When special appropriations are ordered by the Society, they shall not take effect until they have been referred to the Council and Finance Committee in conference.

ART. 29. It shall be the duty of the Publication Committee to receive all papers contributed, and to decide upon which papers or parts of the same shall be presented at the professional meetings of the Society. They shall see that all editorial revisions of the proceedings, papers, discussions, and reports are made; and to decide what parts of the same shall be published in the proceedings of the Society. The Council may, at its discretion, revise any action of the Publication Committee.

ART. 30. It shall be the duty of the Library Committee to take charge of the collection of all material for the Library of the Society, and to supervise all regulations for its use.

ART. 31. At the regular meeting preceding the annual meeting a nominating committee of five members, not officers of the Society, shall be appointed, and this committee shall, at least thirty days before the annual meeting, send to the Secretary the names of nominees for the offices falling vacant under the rules. In addition to such regularly appointed committee, any other five members or associates, not in arrears, may constitute an independent nominating committee, and may present to the Secretary, at least thirty days before the annual meeting, all the names of such candidates as they may select. All the names of such independent nominees shall be placed upon the ballot list, with nothing to distinguish them from the nominees of the regular committee, and the Secretary shall at once mail the said list of names to each member and associate in the form of a letter ballot, it being understood that the assent of the nominees shall have been secured in all cases.

ART. 32. In the election of Vice-Presidents, each member and associate may cast as many votes as there are Vice-Presidents to be elected. He may give all these votes to one candidate, or distribute them among more, as he chooses. Managers shall be voted for in the same way.

ART. 33. Any member or associate entitled to vote may vote by retaining or changing the names on said list, leaving names not exceeding in number the officers to be elected, and returning the list to the Secretary—such ballot enclosed in two envelopes, the inner one to be blank and the outer one to be endorsed by

the voter. No member or associate in arrears since the last annual meeting shall be allowed to vote until said arrears shall have been paid.

ART. 34. The said blank envelopes shall be opened by tellers at the annual meeting, and the person who shall have received the greatest number of votes for the several offices shall be declared elected.

MEETINGS.

ART. 35. The annual meeting of the Society shall be held on the first Tuesday in December of each year, in the City of New York, unless otherwise ordered, at which a report of proceedings and an abstract of the accounts shall be furnished by the Council. The Council may change the place of the annual meeting, and shall, in that case, give timely notice to members and associates.

ART. 36. Other regular meetings of the Society shall be held in each year at such time and place as the Council may appoint. At least thirty days' notice of all meetings shall be mailed by the Secretary to members, honorary members, associates and juniors.

ART. 37. Special meetings may be called whenever the Council may see fit; and the Secretary shall call a special meeting at the written request of twenty or more members. The notices for special meetings shall state the business to be transacted, and no other shall be entertained.

ART. 38. Any member, honorary member or associate, may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

ART 39. Every question which shall come before the Society shall be decided, unless otherwise provided by these rules, by the votes of a majority of the members and associates present, provided there is a quorum.

ART. 40. At any regular meeting of the Society thirteen or more members and associates shall constitute a quorum.

ART. 41. Unless otherwise ordered, papers shall be read in the order in which their text is received by the Secretary. Before any paper appears in the *Transactions* of the Society, a copy of the paper shall be sent to the author, and, so far as possible, a copy of the reported discussion shall be sent to every member

who took part in the same, with requests that attention shall be called to any errors therein.

Art. 42. The Society shall claim no exclusive copyright in papers read at its meetings, nor in reports of discussions, except in the matter of official publication with the Society's imprint, as its *Transactions*. The Secretary shall have sole possession of papers between the time of their acceptance by the Publication Committee and their reading, together with the drawings illustrating the same; and at the time of such reading, or as soon thereafter as practicable, he shall cause to be printed, with the authors' consent, copies of such papers, "subject to revision," with such illustrations as are needed for the *Transactions*, for distribution to the members and for the use of technical newspapers, American and foreign, which may desire to reprint them in whole or in part. The policy of the Society in this matter shall be to give papers read before it the widest circulation possible, with the view of making the work of the Society known, encouraging mechanical progress, and extending the professional reputation of its members.

Art. 43. The author of each paper read before the Society shall be entitled to twelve copies, if printed, for his own use, and all members shall have the right to order any number of reprints of papers at a cost to cover paper and printing; *provided*, that said copies are not intended for sale.

Art. 44. The Society is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions, at its meetings; and it is understood that papers and discussions should not include matters relating to politics or purely to trade.

Art. 45. These rules may be amended, at any annual meeting, by a two-thirds vote of the members present; *provided*, that written notice of the proposed amendment shall have been given at a previous meeting.

CONTENTS OF VOLUME XIX.

LIST OF ILLUSTRATIONS.

PAPERS

OF THE

NEW YORK MEETING

(XXXVIth)

NOVEMBER 30th TO DECEMBER 3d, 1897.

BEING ALSO THE EIGHTEENTH ANNUAL MEETING OF THE SOCIETY.

DCCXLIX.

PROCEEDINGS

OF THE

NEW YORK MEETING

(XXXVIth)

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

November 30th to December 3d, 1897.

THE eighteenth annual meeting of the Society (being also its thirty-sixth convention) was held in New York City during the period November 30 to December 3, 1897. The sessions for papers were convened in the auditorium of the Society's house, 12 West Thirty-first Street, and in the parlors and library adjoining the meeting hall a large number of guests and visitors was always to be found.

The opening session was called to order about nine o'clock on Tuesday evening by the Secretary of the Society, who, after a few words of greeting in the name of the New York members, read a letter just received from Mrs. R. Anna Cary, widow of the late Alanson Cary, as follows:

14 WEST 77TH STREET.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS,
12 West 31st Street, New York.

Gentlemen.—The portrait of Robert Fulton, painted by himself, which was loaned to you two years ago by Alanson Cary, I now wish to present to the American Society of Mechanical Engineers, in his memory, feeling that it would be his desire to have me do so.

Hoping that this gift may prove acceptable, I remain,

Very truly yours,

R. ANNA CARY.

November 30, 1897.

On motion, the Society directed that a resolution of thanks should be transmitted to Mrs. Cary by the Secretary, and that suitable memorial inscription be placed upon the portrait of Robert Fulton, which was hanging over the chair of the President, at the end of the auditorium.

The meeting was then turned over to the President of the Society, Mr. Worcester R. Warner, of Cleveland, who, before proceeding to the delivery of his annual address as President, appointed the tellers, required under Article 34 of the Rules, to count the ballots cast for officers to be elected at this meeting. Messrs. George I. Rockwood and E. N. Trump were appointed to this duty, and the President then proceeded to his address. It was entitled "The Telescope Considered Historically and Practically," and was illustrated by well-chosen lantern slides from interesting sources, which were exhibited at the close of the formal reading of the paper. A contribution by Mr. John A. Brashear on the subject of "Optical Glass" was appended to the address, but was not read in full, owing to the lateness of the hour. At the close of the address and its illustrations the Society took a recess until the following morning, and the remainder of the evening was devoted to social reunion, with a large number of members in attendance.

Second Day. Wednesday, December 1st.

The regular sessions of the annual meeting of the Society began with the meeting of this morning, at ten o'clock, in the Society's auditorium. The large number already registered indicated that the numerical success of the meeting was assured. The plan was again adopted of numbering the lines on the official register and providing that a monogram button badge worn at the convention should bear a number corresponding to the number on the register. Transcripts from the official register were printed at short intervals and distributed to the members, so that it will be apparent that every one could immediately ascertain the name of any other member present, without the embarrassment of a direct question, and the result showed that, in spite of its great size. the meeting was one of the most successful on its social side. The register showed the following persons in attendance from the list of members. The total registered, including guests, was six hundred and ten.

Ackerman, W. S.
Alberger, Louis R.
Albree, C. B.
Aller, A.
Almirall, J. A.
Almond, Thos. R.
Almy, Darwin.
Archer, E. R.
Ashley, F. M.
Ashworth, Daniel.
Bagg, Sam'l F.
Bailey, W. H.
Baker, Chas. W.
Baldwin, Stephen W.
Ball, Frank H.
Bang, H. A.
Bardwell, A. F.
Barnard, Geo. A.
Barnes, Abel T.
Barr, John H.
Barr, H. P.
Bartlett, Geo. B.
Basford, Geo. M.
Batchelor, Chas.
Bates, Alex. B.
Bates, Ed. P.
Bauer, Chas. A.
Baylis, R. N.
Beaman, E. A.
Beardsley, Arthur.
Billings, Chas. E.
Binsse, Henry B.
Bird, W. W.
Birkinbine, John.
Blake, John H.
Blanchard, G. W.
Boenig, R. W.
Bond, Geo. M.
Bone, Wm. H.
Bonner, W. T.
Bourne, Stephen N.
Boyer, Francis H.
Braine, B. G.
Brashear, John A.
Bray, C. W.
Bristol, W. H.
Brown, F. G., Jr.
Brown, L. L.
Brown, R. S.
Brown, Wm. Clinton.
Bulkley, Henry W.
Burchard, A. W.
Cadwell, Wm. D.
Caldwell, A. J.
Carlton, Newcomb.
Carpenter, A. H.
Carpenter, R. C.
Cary, A. A.
Cassier, Louis.
Chase, Wm. L.
Cheney, Walter L.
Christensen, A. C.
Clarke, Sam'l J.
Cogswell, Wm. B.
Cole, F. J.
Colvin, F. H.
Colwell, A. W.
Comly, Geo. N.
Connell, Jas. A.
Connelly, J. A.
Conover, E. K.
Conrad, H. V.
Corbett, Chas. H.
Coster, E. L.
Cowles, W. B.
Cox, J. D., Jr.
Crain, J. J.
Cremer, Jas. M.
Cruikshank, Barton.
Cullingworth, Geo. R.
Curtis, R. E.
Dale, O. G.
Dallett, W. P.
Darling, Ed. A.
Darrin, D. H.
Davis, L. K.
Dean, F. W.
Deane, Chas. P.
Derbyshire, Wm. H.
Dinkel, Geo., Jr.
Dodge, Jas. M.
Doran, W. S.
Doty, Paul.
Dow, Alex.
Dunn, Chas.
Durfee, W. F.
Earll, Charles I.
Edson, Jarvis B.
Edwards, J. I.
Ehlers, Peter.
Emery, Chas. E.
Evans, Quimby N.
Ewer, R. G.
Faber du Faur, A.
Ferguson, Geo. R.
Fish, Chas. H.
Fisher, Clark.
Fladd, Fred. C.
Flagg, Stanley G.
Fletcher, Andrew.
Flinn, Thos. F.
Flint, B. P.
Floyd, Fred. W.
Forbes, Wm. D.
Foster, E. H.
Francis, Harry C.
Freeman, John R.
Frevert, H. F.
Frith, Arthur J.
Fritz, John.
Gale, Horace B.
Garfield, L. M.
Giles, C. E.
Girvin, C. J.
Goetz, F. A.
Goubert, A. A.
Gould, W. V.
Granger, A. S.
Green, S. M.
Greene, D. J.
Greenleaf, G. E.
Greensmith, James E.
Grimm, Paul H.
Guelbaum, David.
Hale, R. S.
Hall, F. A.
Halsey, F. A.
Hamilton, J. V.
Hammer, W. J.
Harding, F. W.
Hartness, James.
Haskins, H. S.
Hawkins, John T.
Hawkins, W. C.
Henderson, Alex.
Henning, Gus C.
Hibbard, H. D.
Higgins, C. P.
Hill, Warren E.
Hillard, Chas. J.

Hoffecker, W. L.
Holly, E. P.
Hoppes, John J.
Horstman, H. J.
Hough, David L.
Howe, H. M.
Hunt, Alfred E.
Hunt, Charles Wallace.
Hunt, Wm. F.
Huson, W. S.
Hutton, Fred. R., Sec.
Idell, Frank E.
Ingersoll, Winthrop.
Jacobs, W. S.
Jacobus, D. S.
Jenks, L. H.
Jennings, E. L.
Johnson, A. E.
Jones, E. H.
Jones, F. C.
Kafer, John C.
Katte, E. B.
Kaven, M. B.
Kearney, Alex.
Keep, Wm. J.
Kenrick, A. E.
Kent, E. C.
Kent, Wm.
King, C. C.
Kirchhoff, Chas.
Knight, A. F.
Kuhn, Joseph.
Laforge, F. H.
Langlotz, Chas.
Lenssen, Arthur, Jr.
Leonard, T. S.
Lewis, D. J., Jr.
Lieb, John W.
Lodge, Wm.
Longnecker, C. K.
Lord, H. F.
Loring, C. H.
Loveland, J. W.
Low, F. R.
Ludlow, W. O.
Lufkin, E. C.
Lyall, Wm. L.
McBride, James.
McCaffery, R. S.
McDuffie, C. D.
McElroy, Samuel.
McEwen, J. H.
McGill, C. F.
McKee, J. J.
McMannis, Wm.
Mackintosh, F.
Main, Chas. T.
Manning, Chas. H.
Mantine, C. F.
Martinez, M. J.
Marx, Henry.
Matlack, John R.
Mattes, Wm. F.
Mayo, John B.
Meatz, John T.
Mellin, Carl J.
Mesta, Geo.
Meyer, H. C., Jr.
Miller, Alex.
Miller, Fred. J.
Miller, L. B.
Miller, Spencer.
Mitchell, B. M.
Moeller, Franklin.
Monaghan, Wm. F.
Montgomery, H. M.
Moore, D. G.
Moore, M. F.
Morehouse, W. S.
Morgan, C. H.
Morgan, P. B.
Morison, Geo. S.
Morse, Chas. M.
Moultrop, Leslie.
Muller, M. A.
Muller, T. H.
Mumford, E. H.
Nash, Lewis H.
Nason, Carlton W.
Newcomb, Chas. L.
Newhall, John B.
Nichols, O. F.
Nicoll, Chas. H.
Norris, H. M.
Norris, J. H.
Odell, Wm. H.
Oviatt, D. B.
Parks, E. H.
Parsons, H. de B.
Patterson, A. W., Jr.
Paul, J. W.
Pearson, Wm. A.
Perkins, T. C.
Phillips, Franklin.
Phillips, Geo.
Phipps, C. W.
Plamondon, C. A.
Platt, John.
Plummer, Frank J.
Pomeroy, L. R.
Porter, Chas. T.
Pratt, C. R.
Quimby, W. E.
Rand, Addison C.
Randolph, L. S.
Raque, Philip E.
Reist, H. G.
Rennie, Robt.
Rettew, C. E.
Rice, Arthur L.
Richards, Chas. R.
Richards, F. H.
Richards, Frank.
Richmond, Geo.
Ridsdale, T. W.
Riesenberger, A.
Riker, A. L.
Roberts, Wm.
Rockwood, Geo. I.
Roelker, H. B.
Rogers, W. S.
Rohrer, A. L.
Ross, E. L.
Rowland, A. E.
Rowland, C. B.
Rowland, T. F.
Russel, Walter S.
Sabin, A. H.
Sahlin, Axel.
Sanguinetti, P. A.
Sattler, W. R.
Schaum, O. W.
Scheffler, F. A.
Schoenborn, W. E.
Schnuck, E. F.
Schumann, Francis.
Schutte, Lewis.
Seamen, H. B.
Seaver, John W.
Sewall, M. W.

Shipley, Thos.	Torrance, Kenneth.	Wheeler, F. M.
Slater, F. R.	Torrance, Henry, Jr.	Wheeler, Schuyler S.
Smith, H. W.	Torrey, H. G.	Wheelock, Jerome.
Smith, Oberlin.	Trautwein, A. P.	Whitehead, Geo. E.
Snell, H. I.	Trask, G. F. D.	Whitham, J. M.
Sornborger, E. C.	Trump, Chas. N.	Whitney, E. H.
Sparrow, E. P.	Trump, Ed. N.	Whittier, Chas.
Spaulding, H. C.	Tucker, Wm. B.	Wiggin, W. H.
Spies, Albert.	Turner, John	Wilcox, John F.
Spilsbury, E. G.	Twining, W. S.	Wiley, Wm. H.
Stangland, B. F.	Tyler, C. C.	Wiley, Wm. O.
Stillman, F. H.	Ulhenhaut, Fritz.	Willcox, Chas. H.
Stirling, Allan.	Van Derhoef, Geo. N.	Williams, Edmund.
Suplee, H. H.	Varney, W. W.	Williams, Franklin.
Swasey, Ambrose.	Victorin, Anthony.	Wilson, Jas. E.
Sweet, John E.	Waldron, F. A.	Winship, J. G.
Tabor, Harris.	Wall, G. L.	Wolff, A. R.
Taylor, J. T.	Wallace, F. A.	Wood, J. L.
Tenney, A. B.	Warner, W. R., Pres.	Wood, M. P.
Thomas, Chas. W.	Warren, B. H.	Woodbury, C. J. H.
Thompson, E. P.	Washburn, W. S.	Woolson, I. H.
Thompson, H. L.	Watson, H. D.	Woolson, O. C.
Thorpe, R. H.	Watson, Wm.	Wright, J. K.
Thurston, R. H.	Webb, J. B.	Wyman, Horace W.
Tibbals, Geo. A.	Weber, Geo. A.	Yereance, W. B.
Tolman, J. P.	Weber, F. C.	York, H. W.
Tompkins, S.	Wellman, Samuel T.	Young, W. S.

The first business of the General Session was the Annual Reports of the Council and the Standing Committees, which were read by the Secretary, as follows:

ANNUAL REPORT OF THE COUNCIL.

The Council would present to the Society, convened for its annual meeting, the report of business which has been considered by it and of action which has been taken during the year.

Five meetings have been convened for the consideration of regular routine business and action upon new matters affecting the policy of the Society. The routine business has been mostly the consideration of applications for membership which have been received, and the grading of such applicants pursuant to the provisions of the rules and to the judgment of the Council in applying them. The routine of this business has received a certain definiteness by the appointment of a special committee of five of its members to consider these applications as they are received, together with the letters which are forwarded to

the Council as confidential communications concerning candidates, and in addition the sending to the membership at large an announcement of the pending candidacy of the person named upon the submitted list. This procedure is similar to the process of "posting" usual in social and other clubs, and enables the Council and its committee to have additional light over and above that which is contained in the letters received from the proposers of a candidate. The Council would take this occasion to urge upon the voting membership the necessity of writing very fully concerning the candidates in whose election they are interested, and that members should not be contented merely to state that in their judgment a candidate is eligible to a certain grade, without giving substantial reasons for the opinion which they express. The Council has, furthermore, directed the Secretary, in cases where this seems advisable, to communicate with members resident in the city or town in which the candidate may reside, to inquire concerning his standing and esteem in the community in which his work is done.

Two interesting applications have been received upon which the Council has not felt itself able to take final action. One was from a gentleman who had been sent to this country by the Chinese government to study mining engineering, and after a course at Lafayette College had been recalled to China, and now occupies the position of chief engineer of one of the considerable collieries of the North Province. The other application was received from the head of an important firm conducting engineering business in Madras, India. Both of these gentlemen were eligible in their several grades, under the provisions of the rules, but by reason of their remote residence they were not acquainted with the five members of the Society necessary under these same rules to act as their proposers. The Council has accordingly directed the Secretary to draft an amendment to the rules which shall provide, under the proper restrictions, for the submitting of such candidates to the membership in the absence of the personal acquaintance which is required from candidates resident in North America. The terms of the proposed amendment, which has received the approval of the Council, are as follows, and the matter will be brought up in its proper place during the convention :

Resolved, That at the end of Article X. of the Rules of the Society there be added the following paragraph :

"Applications for membership from engineers who are not resident in North America, and who may be so situated as not to be personally known to five members of the Society, as required in the foregoing paragraph, may be recommended for ballot by five members of the Council, after sufficient evidence has been secured which shall show that in their opinion the applicant is worthy of admission to the grade which he seeks."

The present membership of the Society, including the names which have been passed to be balloted for previous to this annual meeting, is as follows:

Honorary members	16
Members	1,365
Associates	119
Junior members	323
Total	1,823

The Council has received many applications from the libraries of technical schools and other educational institutions, as well as from Public or State Libraries, for the receipt of its volumes of *Transactions* as a gift. The Council has appreciated the compliment which is paid by these applications and has felt in the past desirous of meeting the wishes embodied in such requests, in view of the benefits which the papers of the Society may be expected to confer and the advantages which would accrue to it if it were well and favorably known to any users of such libraries. The difficulty, however, which has been introduced into the Society's practice by the gradual increase in the numbers who have been receiving such gifts and who may expect, on the grounds of precedent, that a similar application would be granted to them, has forced the Council to an attitude which it regrets, but which seems to be a necessity of the case. The following resolution embodies the action which was taken and will represent for the present and the immediate future the attitude of the Society towards applications of this sort:—

Resolved, That all college and educational institutions (except State or Public Libraries supported by taxation) which should hereafter request that future volumes of the *Transactions* of the Society should be sent to them, should be required to comply with the general provision, and that such volumes will in the future be disposed of to such institutions at the half rate which is allowed to members; viz., in paper binding, $5.00; in half morocco binding, $6.00.

Resolved, That in the case of such institutions as are now receiving the volumes of the Society's *Transactions* gratuitously, or without an equivalent in exchange, under previous resolutions and other actions of the Council, a notice be sent that the Council has directed that this arrangement expire with the issue

of the Society's *Transactions* for the year 1899, and that the issue of the volume for 1900 come under the foregoing resolution.

Resolved, That similar institutions desiring to purchase back volumes of *Transactions* to complete their sets be permitted to do so at the regular member's rates of $5.00 in paper covers and $6.00 per volume in the morocco binding.

At a later meeting, October, 1897 :

Resolved, That State or Public Libraries which derive their income from taxation be allowed to procure back volumes or the current and future issues at the usual rates to non-members; viz., at $10.00 per volume in paper binding and $11.00 per volume in half morocco.

The Council and the Society have been advised, through Mr. Wm. J. Hammer, President of the International Conference on Standard Electrical Rules, that the conference and the other societies which were contributory to the conference have accepted the proposed standard, of which copies have been furnished to us for limited distribution to those interested. The conference requests that this Society will take the usual action which is customary in such cases, and the Council have directed that the communication of Mr. Hammer should be read at the annual meeting, and the report of Mr. C. J. H. Woodbury, member of the Society, as a delegate to represent the Society at the conference, and on whom was conferred the honor of being made its secretary, should be made matters of business for the annual meeting.

Pursuant to the provisions of an agreement entered into between the Society and Mr. Oberlin Smith, the Society has become the owner, by assignment, of the design patent taken out by Mr. Oberlin Smith for the oval form of the standard decimal gauge for measuring and indicating the thickness of metals, sheet and wire, by thousandths of an inch, the number of thousandths being the number of the notch in the edge of the oval gauge. It is not the intention of the Society to derive any business advantage from the ownership of this patent, but merely to protect the decimal gauge from abuse in unauthorized hands. In carrying out this purpose the Society has given manufacturer's license to the firm of Pratt & Whitney of Hartford, Conn., and will be glad to make a similar arrangement, upon request, with other firms of good standing.

It has been found to be of sufficient advantage to the Society and the profession of mechanical engineering in America to have the Society officially represented in the conferences which occur at stated intervals to discuss uniform methods of test and test-

ing materials. These conferences are international in character, so far as the European nations are concerned, and are held at biennial intervals in some European city. The previous conference in September, 1895, had been held at Zurich, and the Society had been represented there, and it was thought advisable that it should also be similarly represented at the conference of August, 1897, at Stockholm in Sweden. In carrying out this intention Mr. Gus C. Henning, Secretary of the Society's Committee on Uniform Methods of Test and Testing Materials, and reporter of that committee, was appointed a delegate of the Society, and was instructed to take the necessary steps to have the Society become an enrolled member of the conference. This procedure gives the Society, through its delegate, a right to vote upon questions brought up in the conference, and the provisions of the conference entitle delegates to one vote for each four hundred members whom he represents. A report from the Society's delegate will be made a matter of business of the annual meeting, and the Council would take this occasion to express the indebtedness which it feels to Mr. Henning, its delegate, for the time which he has sacrificed, without compensation, to meet this assignment of duty. The Society has only been called on to meet the travelling expenses of its delegate.

In this connection the Council has considered the proposition as to the appointment of a conference Committee on Standard Specifications for Iron and Steel, as reported in the Proceedings of the Hartford Convention, as upon pages 652 and 653 of volume xviii. of its *Transactions*. In accordance with the action taken at Hartford, this subject will be made a special order for one of the sessions of the New York meeting, pursuant to a circular notice issued in July, 1897, whereby members were advised upon this point.

Under the provisions of Articles 9 and 16 of the Rules, Mr. George Westinghouse of Pittsburg was nominated by competent persons, and after the lapse of the statutory period a letter ballot of the Council was taken, and the distinction of honorary membership was by unanimous vote conferred upon Mr. Westinghouse.

The Council has been earnestly invited to give favorable consideration to the holding of the spring meeting of 1898 in the city of Omaha, Neb., during the continuance of the Trans-Mississippi Exposition. It seemed advisable to choose a location for the spring meeting which should be nearer the centre

of the average residence represented in the membership, and for this reason the invitation has been declined, and the Council are giving favorable consideration to the holding of the spring meeting of 1898 at Niagara Falls in New York State.

The Council will also report for record the deaths, since the last annual meeting, of the following persons :

B. M. Harris, May 2d ; Robert J. Gilmore, July 2d ; J. T. Ridgway, August 27th ; Robert E. Marshall, November 30th ; David L. Barnes, December 15, 1896 ; Francis A. Walker (Hon. Member), January 5th ; John B. Clements, March 17th ; John Thomas, March 19th ; J. K. Hallock, April 2d ; T. R. Foster, April 15th ; George H. Platt, May — ; John H. Cooper, May 9th ; James E. Grist, May 21st ; De Volson Wood, June 26th ; Henry R. Stone, July 5th ; Charles H. Parker, August 31st ; A. L. Ide, September 30th ; N. R. Weaver, October 5th ; Jos. Cottier, October 10th ; E. H. Booth, October 24, 1897.

The Council would also present for record the report of its tellers, appointed to count the ballots cast for members seeking to connect themselves with the Society just previous to the annual meeting. The report is as follows :

REPORT OF TELLERS OF ELECTIONS.

The undersigned were appointed a committee of the Council to act as tellers, under Article 14 of the Rules, to scrutinize and count the ballots cast for and against the candidates proposed for membership in their several grades in the American Society of Mechanical Engineers and seeking election before the XXXVIth Meeting, New York, 1897.

They have met upon the designated day, in the office of the Society, and have proceeded to the discharge of their duty. They would certify, for formal insertion in the records of the Society, to the election of the following persons whose names appear on the appended list, in their several grades.

There were 415 votes cast on the green ballot, of which 15 were thrown out because of informalities. The tellers have considered a ballot as informal which was not indorsed with an autographic signature, or where the endorsement was made by a facsimile or other stamp.

JOHN C. KAFER,
W. F. DURFEE,
GUS. C. HENNING, } *Tellers of Election.*

AS MEMBERS.

Brenner, Wm. H.	Murphy, Fredk. E.	Stiefel, R. C.
Dunn, Chas.	Potter, Wm. B.	Thorpe, Robt. H.
Hussey, Oren S.	Robinson, H. B.	Tower, A. B.
Johnston, C. R.	Shaw, Geo.	Twining, Wm. S.
Lopez, D. H.	Snyder, J. W.	Tyler, Chas. C.
Moulton, Wm. H.	Starkweather, Wm. G.	Wessinger, H. J.

AS ASSOCIATES.

Brooks, Thos. M.	Marks, L. S.	Winther, C. A. G.
Challen, Paul J.	Schnuck, E. F.	Wurts, Ed. V.
Cooke, Harte	Shepard, L. A.	Woolson, Wm. D.
	Wallace, Jos. H.	

PROMOTION TO FULL MEMBERSHIP.

Albree, Chester B.	Hall, Fredk. A.	Huff, S. W.
Gorton, J. C.		Mount, Wm. D.

AS JUNIOR MEMBERS.

Ashworth, A. K.	Cheney, H. W.	Lauder, Geo. B.
Amsler, W. O.	Heisler, F. Wm.	Matthew, J. G.
Bateman, E. L.	Hill, John H.	Morse, Chas. H.
Boyer, Edwin S.	Hofmann, Alwin	Schuttler, Carl
Brinsmade, L. L.	Koch, Chas. Fredk.	Torrence, Henry, Jr.
	Leonhard, T. S.	

At the close of the report of the Council the second order of business was the Report of the Finance Committee, which was as follows:

For the fiscal year, 1896-97, the Finance Committee of the American Society of Mechanical Engineers would respectfully report to the Council and the Society the following statements of the receipts and expenditures which have passed under their direction on behalf of the Society during the year beginning November 15, 1896, and ending November 15, 1897.

ANNUAL REPORT OF THE FINANCE COMMITTEE OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, 1896-97.

Receipts.

Initiation Fee	$2,180 00
Current Dues	22,031 90
Past Dues	758 68
Advance Dues	218 25
Sales of Publications	1,066 81
Binding	14 50
Engraving	161 35
Carried forward	$26,431 49

Brought forward	$26,431 49	
Life Membership (cash)	300 00	
Interest on Investment	1,110 00	
Office Expenses	50	
Mail and Express	50	
Meetings	16 75	
Badges	450 00	
Total Receipts	$28,309 24	
Cash on hand first of year	76 07	
		$28,385 31

Disbursements.

General Printing and Stationery	$1,430 55	
Reprints and Publications	6,713 81	
Postage and Express	1,851 00	
Salaries	6,805 00	
Office Expenses	355 81	
Engraving	1,771 63	
Contingencies	53 86	
Binding	1,530 90	
Meetings	1,209 70	
Work of Committees	469 00	
House Supplies and Furniture	451 62	
Badges and Certificates	545 95	
Travelling	88 39	
Insurance and Safety Deposit	58 42	
Rent, Interest, and Taxes	3,003 32	
Investment, Bonds Purchased	1,800 00	
Library, (Book Purchase, Binding, etc.)	198 75	
Total Disbursements	$28,337 71	
Cash on hand to balance	47 60	
		$28,385 31

The receipts on account of life membership during this year were, as shown above, $300, which amount was paid by two men, one paying the entire amount for a life membership, $200, and the other $100 on account, the transaction being unfinished to date.

Of the issue of bonds, in 1890, of the Mechanical Engineers' Library Association, which amounted to $32,000, the Council of the Society, as Trustees, held November 15th, 1896, at the time of the last report of the Finance Committee, $21,600, and during the year 1896–97 the Council has acquired $1,800 additional bonds by purchase, thus making $23,400 so held by the Council, and leaving $8,600 of them still outstanding in the hands of members.

At the time of this report there remains outstanding uncollected accounts due the Society as follows:

138 members (less than 8 per cent. of the entire membership) owe for dues, publications, etc.	$3,539 85
9 non-members owe for publications and electros (all recent accounts)	28 67
Total uncollected	$3,568 52

Of the 138 members owing this $3,539.85, three owe small amounts for publications, etc., only recently sent them, and of the remaining 135 members, personal letters have been written to 75, and circular letters sent to the rest, and letters have been received from 65 saying that they would remit shortly, or by a fixed date, or else for valid reasons asking for an extension of time to meet their indebtedness, which has been granted. This leaves only 70 persons out of a membership of 1,799 who have failed either to pay their dues or write in repect to meeting the accounts against them this year.

An indebtedness against the Society amounting to $3,200.60 remains at this date, mainly in the form of an open account with the printers of the Society's *Transactions*, and a part of which is chargeable to the expenses of the next fiscal year, which will be at once met from the collections for the year 1897–98.

The Council would also present for record the following statement prepared and submitted on behalf of the

MECHANICAL ENGINEERS' LIBRARY ASSOCIATION.

COPY OF THE ANNUAL REPORT OF THE TRUSTEES OF THE MECHANICAL ENGINEERS' LIBRARY ASSOCIATION, 1896–1897.

The summary of receipts and disbursements of the Trustees from November 16, 1896, to November 16, 1897, is appended.

Receipts.

Balance on hand first of year, 1896–97		$48 38
Receipts, Fellowship Fund	$176 00	
" Sinking Fund	480 50	
" Office Rent	3,770 00	
" Room Rent	1,742 66	
" Interest on Investment	10 00	
" Library (Duplicate Book sold)	4 00	
" Investment	200 00	
" State Appropriation	125 00	
Total Receipts		$6,508 16
Total Cash		$6,556 54

Disbursements.

Interest on Mortgage		$1,402 50	
" " Bonds		1,600 00	
Salaries		1,140 00	
Janitorial Supplies		340 28	
Fuel		336 25	
Lighting { Gas	$124 19	516 32	
Lighting { Electric Light	392 13		
Equipment (Furniture, Carpets, etc.)		423 41	
Laundry		285 00	
Insurance and Safe Deposit		17 00	
Library, Binding and Book Purchase		164 95	
Repairs (Painting, Papering, etc.)		325 46	
Contingencies		75	
Stationery and Printing		2 00	
Total Disbursements			$6,553 92
Cash on hand to balance			2 62
Total			$6,556 54

Assets.

House and lot, 12 W. 31st Street, New York City	$65,000 00	
Furniture and Equipment	5,000 00	
Books and MSS	10,700 00	
Bills Receivable (Office and Room Rent, uncollected)	132 50	
" " (Subscriptions to Fellowship Fund, uncollected)	10 00	
" " (Subscriptions to Sinking Fund, uncollected)	5 00	
Total Assets		$80,847 50

Liabilities.

First Mortgage held by N. Y. A. of M	$33,000 00	
Second Mortgage held by Members of A. S. M. E	8,600 00	
Second Mortgage held by Council of A. S. M. E. as an investment	23,400 00	
Total Liabilities		$65,000 00
Excess of Assets over Liabilities		$15,847 50

The only discussion which was presented in the line of these formal reports, was the question by a member as to whether the income was sufficient to keep the Library up to the standard desirable, and the explanation by the Secretary that the real growth in the Library, which kept it in its flourishing condition, was the continual inflow of transactions of societies and the best

technical journals, which were received in exchange for the *Transactions* of the Society, and that, in this view, the present practice of the Library Trustees had been a conservative one in the matter of additions on the reference side of the Library.

The report of the tellers appointed at the session of the previous evening was called for, and was read by the Secretary, as follows:

Your committee appointed to count ballots cast for officers of the American Society of Mechanical Engineers for the year 1897–98 begs to submit the following report:

Total ballots counted	443
" " thrown out on account of want of signatures	48
" " signed with rubber stamps and hence thrown out	4
Total votes cast	495

Of this number there were cast:

For Mr. Chas. Wallace Hunt, for President	440
" " W. R. Warner, for President	2
" " John C. Kafer, for President	1
" " Wm. H. Wiley, for Treasurer	442
" " Chas. Corbett, for Treasurer	1
" " John C. Kafer, for Vice-President	445
" " David R. Fraser, for Vice-President	439
" " Walter S. Russel, for Vice-President	442
" " Jesse M. Smith, for Vice-President	1
" " Wm. H. Wiley, for Vice-President	1
" " James B. Stanwood, for Manager	442
" " H. H. Suplee, for Manager	447
" " George Richmond, for Manager	439

Our count therefore shows that the entire ticket was elected.

Respectfully submitted,

GEORGE I. ROCKWOOD, } *Tellers of Election.*
EDWARD N. TRUMP,

At the completion of this announcement the President called on Mr. Charles Wallace Hunt, President-elect, for a few words of greeting, to which request Mr. Hunt made fitting and brief reply.

The next order of business was the report of Mr. Gus C. Henning, who had been delegated by the Council to represent

the Society and its Committee on Uniform Methods of Testing, at the International Conference upon the general question of "Strength of Materials," which had been convened at Stockholm, Sweden. The Secretary reported that the Society had been made an official member of this conference by the payment of a small fee, whereby the Society was represented not only by a delegate, but by a vote on questions to be decided in this way. The report of the delegate was as follows:

REPORT OF THE PROCEEDINGS OF THE SIXTH CONGRESS OF THE INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS, HELD AT STOCKHOLM, SWEDEN, AUGUST 23-25, 1897.

At the request of the Executive Committee, Prof. L. de Tetmajer, President, called the Congress to order in the Hall of the Knights, and in welcoming the members, three hundred and sixty-one of whom had arrived, with about seventy-five ladies, remarked that the international character had been fully sustained by the great number of countries represented, and called attention to the fact that the principal duty of the present meeting would be the discussion of plans for permanent organization, through which alone the aims and purposes of the Association could be achieved.

Hereupon the President introduced the burgomaster of Stockholm, Dr. E. vonder Laucken, who tendered a hearty welcome on behalf of the Swedish people, pointing out that although Sweden was by no means as important in industrial enterprises as several other countries represented, it nevertheless took a deep interest in the work of the Congress.

Acknowledging the hearty welcome tendered by the city of Stockholm through its burgomaster, the President at once proceeded to business by submitting a part of the by-laws, as drawn up by the Executive Committee, necessary during the meetings of the Congress, as the whole matter would not be fully discussed until the last day.

The matter first to be settled was the procedure to be followed during the sessions and the method of voting.

After a protracted discussion of the subject, it was decided unanimously that the method heretofore used at previous congresses be adhered to, viz.: that each member present should

have but one vote. The definitive method would take effect at the next Congress, to be held at Paris.

Contrary to previous custom, the business of this Congress would be carried on in general as well as sectional meetings.

Sec. I. Relating to metals.

Sec. II. Natural and artificial building stone and their bond materials.

Sec. III. Other industrial materials.

The sectional bureaus were determined by each section in presence of a member of Council, who opens the proceedings.

It was then announced by the President that Mr. A. Carnot, Inspector-General of Mines of France, had presented a voluminous, most valuable work on "Chemical-Analytic Methods of Examinations of Iron," which would be fully reported in the official organ of the Association.

Two other papers were received after the programmes had been printed:

One by Prof. A. Retjö, of Budapest, on "Internal Friction of Solids as an Absolute Property, and the Formulæ Derived therefrom Relating to Tension and Compression Diagrams," and one by Dr. W. Michaelis, of Berlin, on the "Process of Setting of Bond Materials Containing Lime."

It was also announced that Prof. A. Wahlberg would present the paper on "The Development of Structural Materials and Methods of Testing Them in Sweden," because of the sudden death of the Director of the Jernkontoret, Mr. Dellwik.

The following honorable presidents were then declared elected after proper nominations: Belgium, A. Greiner, General Manager, Seraing; Denmark, H. J. Hannover, Professor Royal Technical High School, Copenhagen; Austria, W. Ast, Director of Construction, Northern Railway, Vienna; England, Bennet H. Brough, General Secretary Iron and Steel Institute, London; France, E. Polonceau, Chief Engineer, Paris-Orleans Railway, Paris; Germany, Dir. Peters, German Engineers' Association, Berlin; Holland, H. Baucké, Engineer, Amsterdam; Hungary, C. Banovits, Director Hungarian State Railways, Budapest; Italy, St. Fadda, Engineer, Turin; Luxemburg, A. Dutreux, Engineer, Luxemburg; Norway, H. Krag, Director of Department Roads, Christiania; Portugal, J. V. Mendes-Guerreiro, Engineer, Lisbon; Russia, Prof. N. Belelubski, St. Petersburg; Sweden, R. Åkerman, Stockholm; Switzerland, A. Schraff, Chief Engi-

neer, St. Gotthard Railway, Lucerne; Spain, A. Mayandia, Chief of Battalion of Engineers, Saragossa; United States of North America, Gus C. Henning, Engineer, New York.

It was further announced that Prof. J. Wyckander and Chief Engineer Silversparre had, by order of the Jernkontoret, prepared a paper on "Tests of Resistance of Swedish Materials," from materials in its archives, which had been printed and dedicated to the Congress.

This work contains, in a comprehensive and concise form, most valuable information on all the many investigations made by the Jernkontoret on Swedish iron and steels, and gives a most clear and complete knowledge of those materials for which Sweden is so justly famed. It contains a comparison of records, heretofore only partially published, and is a valuable addition to the literature of steel.

After a short intermission Mr. F. Osmond took the floor to read his paper on "Microscopy of Metals Considered as a Method of Test," which was fully illustrated by colored lantern slides.

The author, upon concluding, was rewarded with tumultuous applause for not only the admirable subject matter, but also the perfectly successful arrangements made, by which alone such a paper could be properly presented to an audience.

After receiving the thanks of the President the discussion was opened by myself, thanking the author for his clear and concise presentation of the subject indicating new methods of test. I pointed out particularly that the methods will permit to learn to know the internal constitution of metals and their alloys, and which will have, more than any others, a fruitful influence on industry and technical sciences.

This paper by Mr. Osmond is of such importance that it will be well to point out its main points.

Chemical analysis, although determining the quantity of component elements in a body, does not define the manner, system, or arrangement of molecules. Metallography investigates the latter, and is divided into three divisions:

1. Determination of component parts; or, anatomical metallography.

2. Determination of composition, form, and dimensions of component parts; or, biological metallography.

3. Study of defective treatment of the materials and effect of admixtures having special influence on quality and properties;

or, pathological metallography. Color and light are pointed out as important characteristics in composition, as well as changes due to treatment in a certain manner.

Under each of these heads the author gives notable instances, showing micrographs of cement steel, silver; forged steel, etched with NO_3H and H_2SO_4; alloys of gold and aluminum, and copper and silver; forged steel, annealed, and heated and quenched at given temperature; 11 per cent. Sn bronzes cast in ingots; the same heated to oxidation, cooled in ingots, as well as in sand; the latter reheated to oxidation; the same quenched at red heat; alloys of Au and Bi treated variously, similar to above, and many others.

The remarkable and clearly defined results are beautifully shown, and although the author does not directly state that "microscopy is a method of test which is reliable," he leaves upon his hearers or readers but one well-defined impression, viz.: that such is the conclusion to be drawn from his researches.

Before proceeding to the next business, it was announced that the entire Council of the Iron and Steel Institute and other English metallurgists, thirty in all, had just been declared elected to membership in the Association. The next subject taken up for discussion was the proposition: "Ways and means are to be sought to introduce uniform specification and methods of inspection of iron and steels of all kinds."

This was discussed by Mr. E. Schroedter, of Düsseldorf, and also in two important papers: one by Director Ast, of Vienna, the other by Engineer Barba, of Paris. The outcome of the discussion was the opinion that the result of the proposition was practicable and obtainable.

Dr. H. Wedding, of Berlin, next addressed the Congress on "The Possibility of Establishing an International Sidero-chemical Laboratory." The speaker dwelt upon the main objects of such a laboratory, viz.: the thorough comparison and determination of degree of accuracy of current methods of analyses of iron, and enunciation of those which are to be used in case of dispute. He points out the purely scientific character of the proposed laboratory, and the exclusion of all technical-commercial control analyses for third parties. As $3,666 had already been subscribed, a beginning could be made with such laboratory, although it could not be equipped completely or its continued existence assured.

Section I. (metals) was organized as follows :

Honorary Presidents: Professor Kick, Vienna, and Chief Building Councillor Wichert, Berlin

Chairman: Councillor v. Borries, Hanover.

Vice-Chairmen: Engineer Roussel, of Malines, Belgium, and Engineer Henning, of New York.

Secretaries: Guérard, of Paris, and Schwerdt, of Munich.

This section discussed in a thorough manner the propositions of an international sidero-chemical laboratory, of standard specifications for quality and inspection of iron and steels, methods of determining extension of ductile materials, standard methods of testing rust-preventing coatings.

Engineer Schwerdt, of Munich, described a new method of determining hardness of metals; Professor Retjö, Budapest, exhibited a microphotographic apparatus; Gus C. Henning, New York, showed and described his pocket recorder for stress-strain diagrams; Engineer Wallin, Gothenburg, exhibited a cylindrical slide-rule.

Section II. (stone and bond materials) was organized as follows:

Honorary Presidents: General Choulatschenko, St. Petersburg, and Engineer Segré, of the Adriatic lines, Ancona.

Chairman: Engineer Guérard, Chief Engineer Port of Marseilles.

Vice-Chairmen: H. Fleiner, Aarau, and Prof. A. Wahlberg, of Stockholm.

Secretaries: Caudlot, of Paris, and Professor Steuberg, of Christiania.

The subjects discussed were the following: "Study of the Relation of Chemical Composition and Weathering Qualities of Natural Building Stone"; report of pipe tests, by Max Gary, of Berlin; "On the Hardening Process of Calcareous Bond Materials," by Dr. Michaelis, Berlin; "On the Determination of Quality of Hydraulic Bond Materials," by Director Meyer, of Mahlstatt; "On Irregularities in the Time of Setting of a Cement," by Dr. Eurich, Carlstadt; "Contribution to the Solution of the Problem of the Standard Consistency of the Standard Mortar"; "Determination of those Conditions by which Approximately Similar Densities may be Obtained in Tension and Compression Samples," by Professor Tetmajer, of Zurich, and Engineer Greil, of Vienna.

After further discussion of the proposed by-laws, Captain O. M. Carter, Engineer Corps, U. S. A., was elected member of Council, as well as Mr. Bennet H. Brough, General Secretary of the Iron and Steel Institute of Great Britain.

This report required no action, but was ordered to be incorporated into the records, and the President thereupon called again upon Mr. Henning for the report upon the special order for this morning. The first was upon the work of the Committee on Standard Tests, which was presented by Mr. Henning as a report of progress, as follows:

Mr. Gus C. Henning.—There has been now obtained some definite information to supplement Mr. Keep's admirable paper, presented at the Detroit meeting, upon the "Cooling Curves of Metals," and published in the Society's *Transactions*, vol. xvi., page 1117. It was there stated that the cast iron expanded during cooling, in a proportion which was practically that of the content of carbon in the material. In connection with these a curve was also given, showing a piece of rail steel which showed an irregularity in its curve, which could not be strictly defined as a cooling curve, or as an expansion of the steel during the process of cooling. Since that time Mr. Victor E. Edwards, Mechanical Engineer of the Morgan Construction Company, has kindly volunteered to make some observations in the steel works for me, and I now have from him a letter which proves conclusively that every piece of steel as it comes from the rolls expands during the cooling process just as cast iron does. This was measured on rods three-eighths of an inch in diameter. These rods were 250 to 255 feet long. Eleven different investigations were made, and as the rods could not be clamped at one end, because they would buckle if they were forced to expand in one direction, they were allowed to expand in both directions, and the extension measured at each end and added together. The total of these expansions of rods varied from $3\frac{1}{4}$ to $4\frac{1}{4}$ inches. The average of these eleven examinations showed that the extension of these 250-feet rods was $3\frac{11}{16}$ inches, and there was no case in which there was not a marked expansion during cooling. So we have confirmation of the work done by this autographic recording apparatus of Mr. Keep's to show that the metal does expand during cooling. This verifies the curve on cooling of steel, and as soon as the laboratories at

Columbia University are in running order again, the furnace, which has been paid for by some generous members of the Society, will be called into play and careful investigations made of steels of different carbon under the effect of heat, both rising and falling, to determine the exact amount of expansion and contraction of parts during heating and cooling, to complete the work of the Committee.

Passing now to the special order which was referred to this meeting by the Society at its Hartford convention (vol. xviii., p. 652), the meeting then took up the question of the desirability of establishing uniform specifications and methods of inspection of metals. Mr. Henning recapitulated the subject as follows:

"At the Zurich Conference on Unification of Testing Materials in 1895, a paper on 'The Desirability of Establishing Uniform Specifications and Methods of Inspection of Metals' was presented by Mr. E. Schroedter (Secretary of the Verein der Ingenieuren and Eisenhuettenleute), and the concluding recommendations were, upon motion, referred to the Council for consideration and action.

"In accordance therewith the Council, at a meeting held in Vienna last year, decided to take up the matter, and appointed a Committee to take action on the subject.

"In February, 1897, I received a letter * from the well-known and famous engineer of Le Creusot, Mr. J. Barba, advising me that he, as Vice-President of such Committee, asked me to name members of a Sub-Committee to be formed in the United States to take up the subject conjointly with the European Committees, and requested that I act on said Committee. When I referred the matter to our ex-President, Capt. R. W. Hunt, he sent the following answer,* in view of which I herewith present the matter for discussion at this time.

"The object is to suggest standard specifications for quality and for inspection of all metals used in engineering, and in such a manner that any new developments in metallurgy or fabrication will not be hindered, and on the other hand to define materials in such a precise manner that proper materials may be obtained for each distinct purpose; such as boilers, engines, bridges, wire (telegraph, trolley, telephone, piano, cables, ropes, suspension bridges, various), railways, axles, tires, guns, bicycles, etc., etc."

* See letter appended hereto.

The correspondence referred to above is appended:

(Translation of Mr. J. Barba's letter.)

PARIS, *February* 5, 1897.

MY DEAR SIR: You know that we are about to organize an International Commission, under the presidency of Mr. Ast, Managing Director of the Northern Railroad, Ferdinand, Vienna, Austria, to study the steps to be taken to establish international uniform rules for determining the quality and inspection of all kinds of iron and steel.

I have been honored by the nomination of Vice-President, and I have been asked with Mr. Ast to propose to the directing committee three or four persons from each of the principal nations, these persons to constitute said commission. I have already named the persons for France. I thought that you would kindly choose several able, willing persons in the United States who would assist us at the same time with yourself.

If you will kindly accept my proposition, I would be under obligations to you to name the three or four persons on whom we could count.

Receive, my dear sir, the assurance of my best sentiments.

(Signed) J. BARBA, 39 Rue Mozart.

CHICAGO, *April* 17, 1897.

Gus C. Henning, Esq., No. 5 Beekman Street, New York.

MY DEAR SIR: I beg to acknowledge yours of the 8th inst., and thank you for the compliment therein expressed.

I fully appreciate the importance of the work outlined, and its weight makes it imperative that the subject should not be treated other than in a serious manner.

Personally, my many engagements in all sorts of directions render it unfit that I should try to serve on the proposed committee. While we have many American engineers who could render good service in the cause, it is hard to find those who are willing or can devote the necessary time to it. Hence it would seem as though it would be better if they could be selected from men who, while possessing knowledge gained from practical experience, are not disturbed by or dependent upon current business engagements. Of course we realize that there will come objections to "Professors," but at the same time I am not certain that they are not the class of people who can best serve in a cause of this kind, particularly if they have been in touch with manufacturing progress and interests.

Assuring you that it will give me pleasure to assist you in this matter, and, if it should not be too late, that we will have an opportunity of discussing it at the coming Hartford meeting of the A. S. M. E.,

I remain, yours truly,

ROBERT W. HUNT.

After reading the report and the letters appended to it, Mr. Henning spoke further as follows:

"At the Stockholm Congress both Mr. Ast and Mr. Barba presented papers on the subject, and it was pointed out that the German engineers and metallurgists had already agreed on

standard specifications and methods of testing material for bridge, structural, boiler, and machinery purposes. In fact, there are very few classes of steel now, except the high-carbon steels, which are not classified under the standard specifications, and it has simplified the work in the steel works to a very material degree, avoids complications, and makes the inspection and acceptance of material very much more simple, at the same time making the material more reliable. I must point out, however, that in Germany especially there is hardly more than a single process for making steel in use, while in our country there are a great many, although at the present time the basic process is being introduced so rapidly that it is a question whether in a few years we will not have practically the same conditions; that is, that our steel, although obtained from different materials, will all be produced by the same process. In this case it would be very simple to provide standard specifications, because steel is fundamentally the same, and becomes different through the operations of the metallurgist. The opinion expressed at the Stockholm Congress was this: That there would be no material difficulty in establishing standard specifications, not only for the quality of the steel, but also for the method of inspecting it at the mills. Of course it is always assumed that the material will be inspected at the mills and not at any time after it has left, when it could not be identified, and for other reasons.

"Of course I must say that the members attending the Congress were not all of them familiar with the actual metallurgical conditions in the United States. But another thing has come to interfere in the solution of the question, and that is this: That the International Association has found it necessary to change its methods of procedure in organizing the national sections of the Association, and the American section, which is to be formed, has been requested to organize so as to keep in touch, because of the difficulty of communicating by letter, and then afterwards disseminating these communications to each individual. Until such time as this Association or its branch or section shall have been organized, no committee can be named to take the action that Mr. Barba proposes in his letter, and of course I myself could not act as the organ of the American section. At the same time, as this work will be taken in hand in a very short while (the organization will certainly be

effected during the winter), practical results will be reached, and I think, in view of the fact that so much work has been done abroad in this direction, it would be well for the Mechanical Engineers' Society to express an opinion on the advisability of assisting a committee, which is to be named by the American section of the International Association on Testing Materials, in order to advance by word and act the interests of unification of standard specifications as much as lies in its power. I am quite convinced that simplification of specifications will help considerably to cheapen materials, because it will, in the first place, lessen the kinds of material that will be called for, and although working under different processes, the results will undoubtedly be very satisfactory in establishing certain grades of material, so that when one grade or another is called for, it is known that the product sent will be the correct thing. If other grades are made intermediate between these, that remains with the engineer to accept or to reject, or for the steel works not to put them on the market, because there is something wrong if they do not get the kind of steel that they tried to get. In view of all this, I think it would be advisable for the Mechanical Engineers to take action in this matter, and certainly to express an opinion on the subject."

The President.—I see several members present who must have strong opinions on such a subject as this. I hope Mr. Charles H. Morgan will give us the result of his observation and experience.

Mr. Charles H. Morgan.—I do not think, sir, that I have given sufficient thought to this matter to express an opinion just now, and I hope I may be excused.

The President.—The list still remains large. I see Professor Thurston.

Prof. R. H. Thurston.—I do not know that there is much that I wish to say or much that I ought to say. The field is one that I have been out of now for so long a time that I feel almost entirely unfamiliar with it. But the work is exceedingly important. It is also exceedingly important that this Society should be represented by those of its members who have made a special study of this branch of engineering. We have quite a number who have given many years of their life to study and experiment in this field, and I am very sure that a committee could be made up, appointed by the President, if you choose, which would represent the Society well, and which would

secure for it all of the results of the work of what is becoming an important international association. There are very few subjects within our purview that are more important than the determination of means, the finding of ways, of securing the best of material and the best of tests of our material, and it can only be done through prolonged scientific research—research carried on by men who are experts—not simply in knowledge of working material, but in the methods of testing material; men who handle their work in the laboratory with the same ease and familiarity that others exhibit when they deal with their work in manufacturing. Our representatives should be men who have had experience in the mills in which the materials of engineering are produced, and who, at the same time, have made themselves familiar with the most scientific methods of making chemical, physical, and mechanical tests of all classes of materials. We can certainly have a good representation there, but I think that time should be taken by the presiding officer, or whoever may appoint this committee, to see that he secures the best men in the Society, and to convince them that it is for them a duty to represent the Society on such a committee.

The President.—Is it your pleasure, gentlemen, that a committee should be appointed, in accordance with the suggestions made by Messrs. Henning and Thurston, to confer with the International Committee, with a view to securing to our Society all the benefits of their work?

Such a motion was duly put and carried, that the chairman should appoint a committee.

The chair announced that this was the time allotted for the presentation of the draft of a report of the committee appointed at the Detroit meeting, June 26, 1895 (vol. xvi., page 645), to consider the wisdom of revising the code proposed in 1885 for the conduct of boiler trials. The discussion of this report, which was submitted by Mr. William Kent on behalf of the committee, was made a feature of two of the sessions. At this morning's session Messrs. Webb, Hale, Carpenter, Rockwood, Dean, Randolph, Gale, Hartness, and Thurston took part. In deference to the views of others, who were unable to be present at this morning's session, the discussion was to be continued on the evening of Thursday.

A request was presented from Messrs. E. M. Herr, W. H. Marshall, and C. H. Quereau, as follows:

NORTHERN PACIFIC RAILWAY COMPANY.

ST. PAUL, MINN., *Nov.* 16, 1897.

Subject: *Lack of Uniformity in Sizes of Pipe Unions, etc.*

SECRETARY AMERICAN SOCIETY MECHANICAL ENGINEERS,
12 WEST THIRTY-FIRST STREET, NEW YORK.

Dear Sir: The attention of the American Society of Mechanical Engineers is directed to the lack of uniformity in the sizes of pipe fittings manufactured by different makers in various parts of this country.

This has been brought forcibly to the attention of the undersigned, and others interested in the mechanical department of railway work, by the trouble, delay, and consequent expense caused by pipe unions, purchased from different dealers for the same purpose, not being interchangeable. The same also is true of pipe threads themselves, although the lack of uniformity is not so great.

This subject has been deemed of sufficient importance by the American Railway Master Mechanics' Association and Master Car Builders' Association for the appointment of a joint committee on this and the related subject of standards for square bolt heads and nuts.

Inasmuch as the desired uniformity can only be secured by concerted action of the large purchasers and consumers of bolts and nuts, pipe and fittings, and those engaged in their manufacture, it would seem desirable that the American Society of Mechanical Engineers should, at the next meeting, appoint a committee to consider these subjects, confer with the committees of the railway associations, and endeavor to secure the appointment of a committee representing the manufacturers, with the object of securing the desired uniformity.

As an example of the present condition of affairs, the diameter and number of threads on union nuts of one-inch pipe fittings, made by seven different manufacturers, are given below:

No. Threads.	Diameter of Threads.
11	2.000 inches.
12	1.875 "
11½	2.000 "
11⅜	1.97 "
12	1.875 "
11⅜	1.8906 "
11⅜	2.1718 "

Yours very truly,

E. M. HERR,
WALDO H. MARSHALL,
CHAS. H. QUEREAU,
Members A. S. M. E.

The Secretary added that, on receipt of the communication, he had written to Mr. Geo. M. Bond, who had been the reporter for the previous Committee on Standard Threads for Pipes, and that Mr. Bond had stated that the question of the threads of these pipe union fittings had not been considered, so that it came

up as a new question, which might properly be considered by that same committee, if thought desirable.

Mr. Dean presented the following resolution:

Resolved, That the American Society of Mechanical Engineers, having received and considered the suggestion of Messrs. E. M. Herr, W. H. Marshall and C. H. Quereau on the subject of securing uniformity in the threads of coupling unions for pipe, approve of the suggestion that the Society should appoint a committee to consider this question in joint conference with similar committees of the American Railway Master Mechanics' and the Master Car Builders' Associations, and refer the appointment of such committee to the Council, with power.

This was amended by Mr. Henning by the suggestion that the matter should be referred by the President and Council to the same committee who had considered the subject of standard pipe threads, if they were willing to act. This amendment was accepted by Mr. Dean, and in the discussion the following remarks were presented:

Mr. John J. Hoppes.—I understood the gentleman to read standardizing of the threads of the unions. Do I understand that the gentleman referred to the standardizing of the unions themselves?

Mr. Lewis H. Nash.—In relation to the water-meter business, in which we are engaged, we have found quite considerable difficulty in making our connections so that they would fit all sorts of plumbers' supplies, and in order to accomplish that we got from the standard makers a large number of samples, and took the average size of those samples, but even then there was such a wide variation in the sizes of threads that we often have reports that our fittings are not the proper size. So I feel very much interested in regard to a standard. But it occurred to me that possibly it would be well for us to have some communication with the plumbers' supply people, as, if unions are to be used universally, steam fitters and the plumbers are the largest users of all such material, and I know there has been a number of attempts by manufacturers to come to some conclusion as to what sizes they would use for pipe fittings. It seems to me that the more extensively we consult large users, the more likely we will be to adopt a standard that will give universal satisfaction.

Mr. Stanley G. Flagg.—We are manufacturers of the article which I imagine is in question—that is, malleable iron pipe unions. The matters referred to were taken up, I think, about five years ago by the mechanical engineers of the Pennsylvania

Railroad Company. They went very exhaustively into standard dimensions of this coupling nut, which slips over the swivel; they also went fully into dimensions for all such fittings used in similar work, and submitted their schedule to us for inspection. We took up the matter very carefully, consulting with them, and after possibly a year or so the matter was dropped.

The dimensions given in that letter which was quoted will show the experience of almost every one. I imagine their figures to refer to the threads in the coupling nut, and I know the lengths of these pieces vary with different makers. The Westinghouse Air Brake Company have a standard of their own for this piece, and the subject, if taken up, would be quite a large one.

Regarding such changes as would be necessary to standardize them, you must bear in mind that it would occasion many changes in special tools with which every maker is provided, and its accomplishment would be a consummation to be wished for by all those handling such goods, and it is a matter, I am sure, which would have to be gone into quite carefully, and not more than five, or possibly seven, makers of these goods would have to be dealt with. From a theoretical standpoint, no doubt they would all agree with this association. Whether it would be possible to put this into practical operation, of course, is something none of us know until we would try.

In its amended form, after this discussion, the motion was carried.

Professional papers were then taken up.

The papers by Messrs. W. W. Christie and by F. W. Dean were entitled, respectively, "Classification of Data and Plotted Results." "Reduction of Cost of Steam Power from 1870 to 1897." The debate upon them was conducted by Messrs. Stirling, Rockwood, Thurston, Mason, Kent, Hale, Carpenter, and Randolph.

THIRD SESSION. THURSDAY MORNING, DECEMBER 2D.

The session was called to order at ten o'clock, and the following papers were presented: By Prof. R. C. Carpenter, entitled "Tests of Centrifugal Pump and Calibration of Weir at the Bridgeport Pumping Station, Chicago"; by Mr. Howard Stillman, entitled "A Water-purifying Plant"; by Prof. R. H.

Thurston, entitled "Multiple-cylinder Engine: Effects of Variation of Proportions and Variable Loads"; by Mr. W. S. Aldrich, entitled "Notes on Rating Electric Power Plants on the Heat-unit Standard," and by Mr. William S. Keep, entitled "Cast Iron Under Impact."

The debate at this session was participated in by Messrs. Thurston, Kent, McElroy, Suplee, Cary, Randolph, Trump, Greene, Rockwood, Durfee, Henning, Newcomb, Hawkins, Ball, Gale, Barr, West, and Kneass.

FOURTH SESSION. THURSDAY EVENING, DECEMBER 2D.

The papers allotted for this evening included the following: By Mr. John B. Mayo, entitled "A Strength of Gear Chart"; by Mr. David Guelbaum, entitled "A Law of Hydraulic Obstruction of Flow in Pipes"; by Mr. George Richmond, entitled "Thermodynamics Without the Calculus"; by Mr. H. M. Norris, entitled "An Accurate Cost-keeping System"; by Mr. Charles T. Main, entitled "The Valuation of Textile Manufacturing Property"; by Mr. W. B. Smith Whaley, entitled "Electricity in Cotton Mills"; by Mr. James Hartness, entitled "Screw Die for the Turret Lathe" and "Stay-bolt Threading Device"; together with a discussion, postponed from Wednesday morning, upon the proposed revision of the code of boiler tests. In consequence of the interest attaching to the discussion of the boiler code, only the papers of Messrs. Mayo and Guelbaum were read, and the discussion on the boiler code was introduced by Mr. Charles E. Emery, who was followed by Messrs. Stirling, Jacobus, Kent, Gale, Henning, Whitham, Cary, Manning, Ashworth, Hawkins, and Kent.

The President took occasion to allude in genial terms to the fact that for many years he, in common with other members of the Society visiting New York City, had been receiving the hospitality tendered to the membership on the occasion of the annual reception held in New York City during the recurring annual meetings, without appreciating that in so doing he was accepting, as were all the members, a personal courtesy extended to the visiting members by the residents of New York City. He thereupon called on Mr. Oberlin Smith to present a resolution which he had drafted, which was done in the following terms:

Resolved, That the heartfelt thanks of the members in attendance at this convention are due, and are hereby tendered, to the New York members of the Society for their generous hospitality in entertaining their guests at the general reception held last evening.

Mr. C. J. H. Woodbury.—In rising to second this resolution I want to say that it has always seemed to me that members of the Society are now, and have always been, deeply grateful to the New York members of the Society for the perennial spring of hospitality which we have always found flowing in the late autumn for our annual meeting. We non-residents may be like the little lad who was reproached for not thanking a generous lady for her gift of candy, who replied that he did thank her, but he had not told her so. It may be that we have not always told the New York members of our thanks, and it seems to me a very proper action to spread a resolution of this sort upon the records of our Society.

Fitting and humorous remarks were made by Messrs. Ashworth and Oberlin Smith, and, on motion, the resolution was adopted.

The President called on Mr. C. J. H. Woodbury, who had been appointed a delegate to represent the Society at the National Conference which had been summoned to consider the preparation of rules and requirements for the installation of apparatus and wiring for electric light, heat, and power. He explained that the Society had tendered to this Conference the use of its rooms for their meetings, and that a ballot letter of recognition had been received and filed from Mr. William J. Hammer, the President of the Conference. Mr. C. J. H. Woodbury had been chosen the Secretary of the Conference, as well as representing the Society in its deliberation. Mr. Woodbury's report was as follows:

REPORT OF DELEGATE TO THE NATIONAL CONFERENCE ON STANDARD ELECTRICAL RULES.

BOSTON, MASS., *October* 1, 1897.

TO THE PRESIDENT AND COUNCIL OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

Gentlemen: In accordance with the vote of the Council:

On motion resolved, "That the American Society of Mechanical Engineers takes pleasure in accepting the invitation from the National Conference on

Standard Electrical Rules, and until further action will send a delegate to future meetings of the Conference;"

Resolved: "That Mr. C. J. H. Woodbury, of Boston, past Vice-President of this Society, be appointed the delegate of this Society to the National Conference on Standard Electrical Rules, until further action by the Council."

The Conference included representatives from the following bodies:

American Society of Mechanical Engineers,
American Institute of Electrical Engineers,
American Street Railway Association,
Associated Factory Mutual Fire Insurance Companies,
National Association of Fire Engineers,
National Board of Fire Underwriters,
National Electric Light Association,
Underwriters' National Electric Association,
National Board of Fire Underwriters,
American Institute of Architects,
International Fire Chiefs' Association,
American Bell Telephone Company,
Western Union Telegraph Company,
Postal Telegraph Company,
General Electric Company,
Westinghouse Electric and Manufacturing Company,

and held a meeting in the Hall of the American Society of Mechanical Engineers on March 18-19, 1895, at which William J. Hammer was elected President; C. J. H. Woodbury, Secretary.

The two days were occupied in a critical discussion of electrical rules, and a record of the conclusions taken and submitted to the following Code Committee:

F. B. Crocker, Chairman, American Institute Electrical Engineers.
William Brophy, { National Electric Light Association. / National Association of Fire Underwriters.
E. A. Fitzgerald, Underwriters' National Electric Association.
William R. Ford, American Street Railway Association.
E. V. French, Factory Mutual Fire Insurance Companies.
W. H. Merrill, National Board of Fire Underwriters.
Alfred Stone, American Institute of Architects.
W. J. Hammer, President of the Conference, ex-officio.

Copies of existing rules were printed in parallel columns, and four hundred and seventy-five copies sent to interested parties, with a communication from the Secretary asking for further comments and suggestions.

The replies were submitted to the Committee on Code, who held numerous meetings, and the result of their labors accepted by the members of the Conference on a letter ballot without reassembling of the body.

The Electrical Committee of the National Board of Fire Underwriters have accepted the suggestions in the identical form in which the rules are now issued by that body under the title of the "National Electrical Code," edition of 1897, and the code has also been accepted by those of the bodies constituting that organization who have held meetings at which action could have been taken on the subject.

In its present form it represents a consensus of opinion by those broadly interested in every department of the subject, and its adoption by the under-

writers and other organizations has accomplished the desired purpose of the unification of rules upon the subject of installation and maintenance of electrical plant.

A copy of the rules is submitted herewith, and forms a part of this report.

Respectfully submitted,

C. J. H. WOODBURY,

Delegate from the A. S. M. E.

At the conclusion of the report Mr. H. H. Suplee presented the following resolutions, which were adopted. The Standard Rules will be made an appendix to the papers of the meeting:

Resolved, That the American Society of Mechanical Engineers have listened with interest to the report of its delegate to the National Conference on Standard Electrical Rules, and his report concerning the National Electrical Code of Rules and requirements for installation of apparatus and wiring for electric light, heat, and power.

Resolved, That the American Society of Mechanical Engineers, pursuant to its approved policy in technical matters such as are concerned in the report of its delegate, accept the report of the Committee of the National Conference, which has been presented to the Society by Mr. Woodbury, and direct that the rules and requirements recommended be printed as one of the papers of this meeting and incorporated into the volume of *Transactions*, and the use of these rules be recommended to the membership of this Society.

FIFTH SESSION. FRIDAY, DECEMBER 3D.

The papers for the morning included certain ones which had been omitted from the regular programme of the previous evening, by reason of the interest attaching to the discussion on the revision of the code of boiler trials, and included the following papers: By Ms. George W. Dickie, entitled "Auxiliary Engines and Machinery for Naval Vessels"; by Mr. George W. Bissell, entitled "A Boiler Setting"; by Mr. H. M. Norris, entitled "An Accurate Cost-keeping System"; by Mr. George Richmond, entitled "Thermodynamics Without the Calculus"; by Mr. Charles T. Main, entitled "The Valuation of Textile Manufacturing Property"; by Mr. James Hartness, entitled "Screw Die for the Turret Lathe" and "Stay-bolt Threading Device"; by Mr. C. J. H. Woodbury, entitled "Dustless Buildings"; by Mr. Andrew Fletcher, entitled "The Stevens Valve Gear for Marine Engines"; by Mr. E. H. Mumford, entitled "Machine Moulding Without Stripping Plates"; by Mr. W. B. Smith Whaley, entitled "Electricity in Cotton Mills"; by Mr. A. L. Rice, entitled "Convenient Form of Wire Testing Machine." The discussions were presented by Messrs. Suplee, Halsey, Rogers, Oberlin

Smith, Randolph, Cary, C. W. Hunt, Kent, Rockwood, Woodbury, Henning, Gale, Archer, Pomeroy, Kafer, Fletcher, Comly, Winship, and Main.

At the conclusion of the last paper the President made graceful allusion to the courtesies which he had received from the members, and expressed the pleasure and grateful memories which he would take with him as a recollection of the treatment which he had received at the hands of the Society and its officers.

The Secretary made mention of the probable occurrence of the next meeting of the Society at Niagara Falls, beginning May 31st. Thereupon the President, on motion, announced the meeting adjourned.

The custom was followed at this meeting which has been the precedent of several previous years, that at the close of the morning session on Wednesday and Thursday a luncheon was served to the members who were in attendance, and who were by this expedient beguiled into remaining during the unassigned hours of the afternoon for conference with each other, and for the discussion of informal questions presented outside of the regular routine of the meeting. No papers were assigned nor excursions allotted to these afternoons, with this definite opportunity in view. On Thursday afternoon Mr. Gus C. Henning presented the results of the recent experiments in photographing in natural colors under the Joly patents and system, throwing transparencies upon the screen in color and illustrating the system with many successful examples.

On Wednesday evening a general reception was tendered by the New York membership to the visiting members and their ladies at Sherry's, Thirty-seventh Street and Fifth Avenue. The members were received by the President in office and by the President-elect, with their ladies, as a reception committee, and after the reception dancing was provided for in the large ballroom. Supper was served during the entire evening, so as to prevent uncomfortable congestion at the table. Upwards of four hundred persons were in attendance.

DCCL.*

THE TELESCOPE CONSIDERED HISTORICALLY AND PRACTICALLY.

BY WORCESTER R. WARNER, CLEVELAND, OHIO.

(President's Address, 1897.)

In the study of the development of the telescope, it may be of interest to recall briefly the state of the science of astronomy up to the time of Galileo's invention.

The ancients had carefully studied the geography of the heavens, and as early as 2000 B.C. we have records of the constellations. In the oldest of the biblical records—the Book of Job—we read: "Canst thou bind the sweet influences of Pleiades, or loose the bands of Orion? . . . or canst thou guide Arcturus with his suns?"

In the second century B.C., Hipparchus, the father of mathematical astronomy, by comparing his own observations with those recorded 147 years earlier, demonstrated that the length of the year, instead of being 365¼ days, as it had hitherto been considered, was 365 days, 5 hours, 55 minutes, 12 seconds. This is the first instance in the history of astronomy where a result was deduced by a comparison of widely separated observations. His result, as determined over 2,000 years ago, is in excess of the correct length of the year by but six minutes.

Later he discovered the precession of the equinoxes, and to him also we are indebted for the first star catalogue, his list comprising 1,088 stars. Ptolemy, who flourished about the middle of the second century, A.D., preserved in his publications the work of Hipparchus, and published the first catalogue of the constellations, forty in number.

Ptolemy is best known to the world as the originator of the Ptolemaic system of the universe. While, as we know, founded on error, this was the accepted theory for more than thirteen

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Vol. XIX. of the *Transactions*.

hundred years, during which time little progress was made in the science of astronomy.

Copernicus, about the year 1550, gave to the world the true theory, claiming the sun as the centre of our system; but it was slow in finding favor, for the Ptolemaic system had become so closely interwoven with the religious belief of the times that any view differing from it was considered heretical. In fact, the Copernican system waited for the invention of the telescope, and consequent verification through Galileo's discovery of the phases of Venus and Mercury.

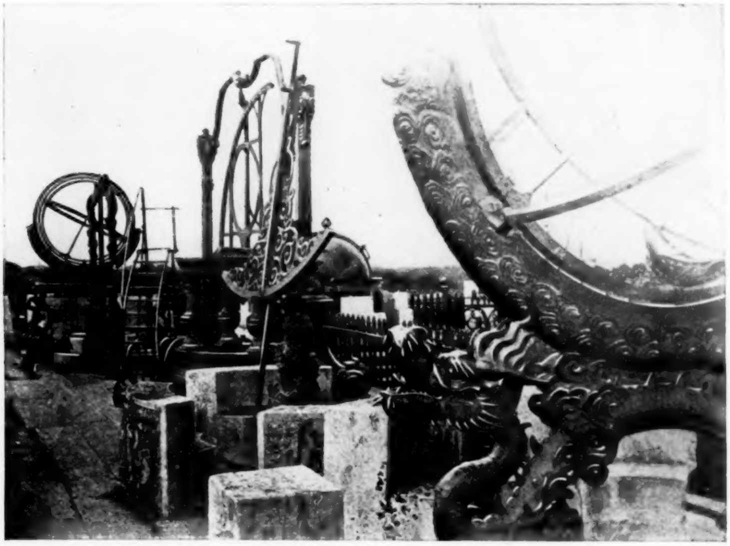

Fig. 1.—Astronomical Instruments on the Walls of Pekin, China.

From the earliest historical mention of astronomy down to the invention of Galileo's telescope in 1610, the science was closely interwoven with superstition in the form of the pseudo-science of astrology; so much so, in fact, that the so-called wise men of the first sixteen centuries of the Christian era were fortune tellers, and based their predictions on the phenomena of the heavens and the position of stars and planets. Some remnants of these ancient astrological beliefs still hold sway over many of our estimable people, for have we not often heard of fond mothers who wait until after the full of the moon before beginning to wean their

babies? And nearly every time the moon presents her beautiful crescent to us in the western sky, we are told that it is either a "wet moon" or a "dry moon." If we happen to have a storm near the 21st of March or of September, it is to this day called the "equinoctial storm," although the position of our earth relative to the sun can have no possible effect on the weather.

The most valuable astronomical instruments previous to the invention of the telescope were constructed in the last quarter of the fifteenth century by order of that most eminent Danish astronomer, Tycho Brahe. By graduated circles and finely made sights he was able to construct a catalogue of 777 stars whose positions were more accurately measured than in the case of any previous catalogue. His very interesting instruments are now preserved in the Royal Palace at Fredericksborg, near Copenhagen.

While we find several accounts of instruments for the purpose of seeing objects at a distance, there seems to be no authentic record of a telescope actually constructed previous to those made in Holland about the year 1609 by Janssen, Metius, or Lipperhey. Different accounts give credit to each of these men, so we will give credit to all. In any case, the Dutch instrument was applied solely to military uses. It remained for the Italian philosopher Galileo to first apply the principle of the telescope to astronomical research.

The earliest telescopes consisted of two lenses held in their relative positions by insertion in a tube. The object glass, or objective, was of double convex form, and the eyepiece was a double concave lens, the distance of these lenses from one another being the difference of their principal foci, just as in the tubes of our cheapest opera glasses of to-day. The modern opera glass, however, magnifies but about 2½ diameters, while Galileo succeeded in making, on this principle, a telescope which magnified 30 diameters. With this he discovered the mountains on the moon, the phases of Venus, and the four satellites of Jupiter. The Dutch inventors called their simple instrument a "trunk," while Galileo speaks of his as the "optic tube" and the "perspective."

The objective of one of Galileo's original telescopes—about 1½ inches aperture—is now, with many other mementoes of that great philosopher, in the Galilean Tribune of the Museum of Natural Sciences in Florence.

A few years after the invention of the Galilean instrument, it was suggested by the German astronomer Kepler that a tele-

scope having two convex lenses would be superior to the form used by Galileo. Kepler, however, did not develop the idea, and we find no important mention of it until the English astronomer Gascoigne discovered, about 1638, that, in addition to seeing a distant object by this form of telescope, he could at the same time clearly see a small object placed in the focus common to the two lenses. To him, therefore, belongs the glory of having first applied to the telescope the basic principle of the micrometer for the measurement of objects and angles. The invention enabled him to make the first telescopic measurements of the sun, moon,

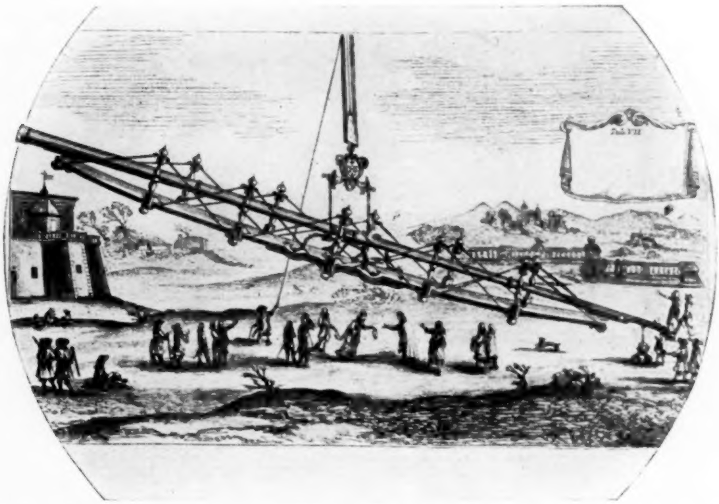

FIG. 2.—A GREAT TELESCOPE OF THE SEVENTEENTH CENTURY, AFTER BIANCHINI.

and principal planets. Unfortunately his career came to an early close, for he died in 1644, at the age of 24.

Two serious optical difficulties, called "chromatic" and "spherical" aberration, caused the earlier astronomers great trouble ; for even in Galileo's telescopes, small as they were, a fringe of rainbow tints surrounded every object viewed, and the objects, too, had a more or less hazy or indistinct appearance, caused by the spherical aberration of the single lens used by him, while the higher the magnifying power the more manifest were these defects. They were more marked, too, in the Keplerian than in the Galilean telescope. The chromatic aberration

was partly overcome and the spherical aberration was reduced by greatly increasing the focal length of the objective. So, while the early Dutch telescopes, as well as those made by Galileo, were but a few inches long, the astronomer Huyghens had, about the year 1655, constructed telescopes varying from 150 to 200 feet long. With one of these he discovered a satellite of Saturn, and later established the fact that the "appendage" which Galileo had described as attending that planet was a ring, probably revolving around it. With one of these long-focus telescopes, too, Cassini discovered the divisions in the ring of Saturn. The glass with which he made this discovery is now carefully preserved in the museum of the National Observatory at Paris.

Gascoigne's invention of the micrometer had not been made known beyond England, but in 1658 the French astronomer Huyghens independently discovered this same principle, and in 1659 applied it by inserting a strip of metal of varying width in the focus of his telescope, and noting at what point it exactly covered the image of the distant object under observation. By carefully measuring the strip of metal and comparing it with the focal length of the objective, he readily deduced the apparent magnitude of the object. In this manner he determined the angular diameter of the planets and the relative positions of many stars.

Improvements on this method of measuring angles were rapid and easy, the next step being the application of a network of silver wires in the focus of the telescope. This was followed in 1666 by the micrometer with movable wires, which is one of the principal forms in use at the present time, though in the gradual refinement of the instrument the metallic wires have long since been replaced, first by fibres of silk, and later by the infinitely delicate web of the spider.

The invention of the micrometer opened an entirely new field for astronomical research. The telescope was no longer merely a revealer of the heavens, but, by the help of the new apparatus, pointing it exactly toward a given object, had become a measuring instrument of undreamed accuracy.

About 1680, Roemer, a Danish astronomer, constructed a telescope having a fixed axis at right angles to the optical axis, and in the focus of which he placed micrometer wires. Thus he invented the form of telescope called the "transit instrument."

To the axis were applied graduated circles, the divisions of which were read by microscopes. Roemer adjusted his instrument in the true meridian, and so first used the telescope for measuring the exact time of the transit of stars across the meridian (Fig. 3).

The limitations to the power of refracting telescopes caused by

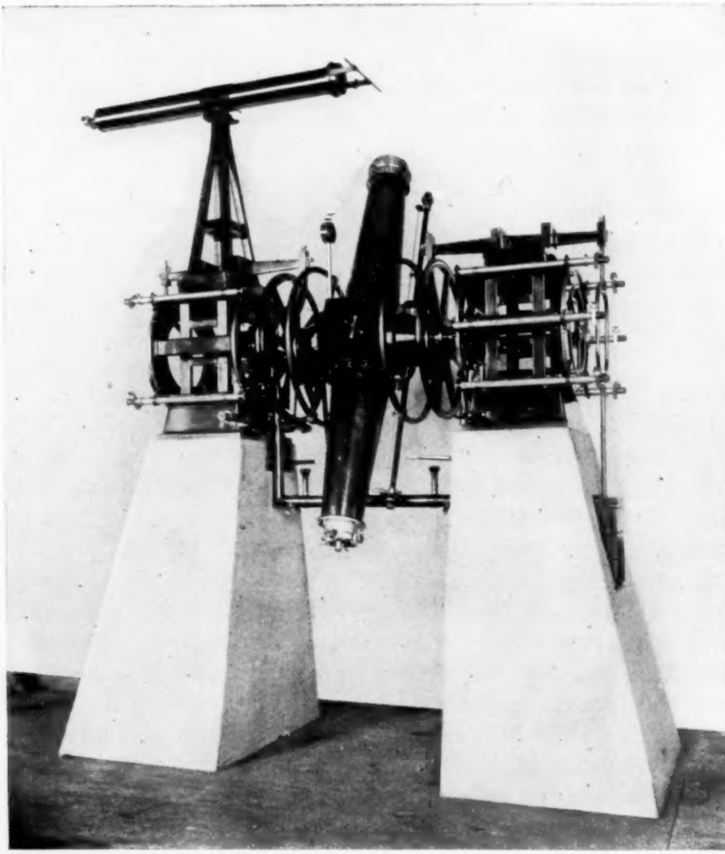

FIG. 3.—SIX-INCH MERIDIAN CIRCLE, U. S. NAVAL OBSERVATORY.

"chromatic aberration," as mentioned earlier in this paper, were most carefully studied with a view to obviating the trouble. Sir Isaac Newton, in investigating the subject, discovered, in 1666, the unequal refraction of the different elements of light, and from that fact deduced the conclusion that any further improvement in the refracting telescope was impossible.

He then turned his attention to the principle of reflecting telescopes, which had been explained by Gregory in 1664, and to Newton must be given credit for having, in 1670, constructed the first instrument of this type. This is now preserved in St. John's College Museum, Cambridge, England.

While the chromatic aberration of the refractor was wholly obviated in the reflector, other equally annoying conditions prevented its general adoption. It was essential that the reflecting surface be a parabola, and none of the earlier opticians could produce that form. Another difficulty lay in the fact that the effect of errors of spherical aberration in the optical surface is four times as manifest in reflectors as in refractors.

Thus we see that both types of telescopes were greatly limited in their efficiency, and the prospect of improvement seemed far distant.

Indeed, though sixty years had passed since Galileo made his first telescope, yet these limitations to the power of instruments, as just explained, so retarded progress that but few astronomical discoveries had been added to those made by him. Nearly a hundred years more were destined to pass before the problem of correcting the chromatic and spherical aberration of the refracting telescope should be solved. During this time much was done toward developing the reflecting telescope.

In 1732 Newton succeeded in constructing the first parabolic mirror, which greatly improved the definition of such instruments. But at last, in 1755, the English optician Dollond discovered that the dispersion of light was variable when refracted through different kinds of glass. With this fact as a key, he constructed object glasses having two lenses of such form and refracting power that one would correct the error of the other, and thus eliminate entirely the spherical aberration as well as the greater part of the chromatic aberration. This invention removed in a very large measure the difficulty which for one hundred and fifty years has been a check to progress in the use of refracting telescopes. Credit is given to Chester Moore Hall, of Essex, England, for having made the first achromatic objective, in the year 1829; but the theoretical as well as the practical development of this great invention is certainly due to John Dollond.

Comparing the two types, reflectors and refractors, it must be said that both have their points of decided advantage; but the serious loss of light and definition in the case of the former rele-

gates it, in the hands of astronomers, to use in very limited directions, and in the hands of amateurs, to the purposes of entertaining the public. Even in the case of so earnest a student as Lord Rosse, it is worth remembering that his best records were made with his three-foot reflector rather than with the famous six-foot. While, therefore, there seems no limit to the development of the refractor, a bound *is* set to the usefulness of large

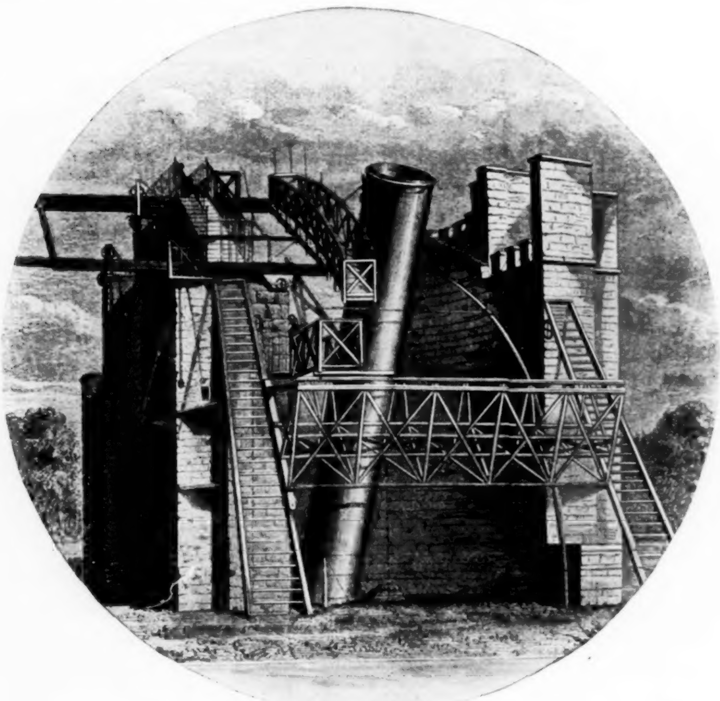

FIG. 4.—LORD ROSSE'S SIX-FOOT REFLECTING TELESCOPE.

reflectors by the impossibility of properly supporting a mirror more than three feet in diameter. Varying flexure results from experimenting with larger specula, so that it is scarcely scientific to expect further development in reflecting telescopes; yet they have their uses, and are found to-day in many of the best-equipped observatories, but only as accessories to the principal instruments.

Each advance in the optical efficiency of the telescope necessitated equal improvement in mechanical means for adjusting and

using the instrument. At first it was simply held in the hand, and even as crude methods of support came gradually into vogue, they were of small use otherwise than as approximately holding the tube in position. Previous to the eighteenth century the best telescopes were used with the alt-azimuth mounting, having, as the name indicates, one motion in altitude and one in azimuth, the combination of these motions enabling the observer to point the instrument to any part of the visible heavens. The apparent *motion* of the stars made the use of this type of mounting very unsatisfactory and inadequate for observing, especially when high magnifying powers were required.

When we remember that it was an astronomer who overthrew the Ptolemaic heresy by demonstrating the Copernican theory, and an astronomer who devised the very form of the telescope, and wrought out the optical problems involved, it is hard to understand why mighty thinkers like these same early astronomers should have stumbled in the design of a mounting which would follow by a single movement the apparent motions of stars and planets. Yet we do not find any mention of the equatorial telescope until Roemer, the Astronomer Royal of Denmark, made one early in the eighteenth century, and we may believe he was the original inventor of this most excellent type of mounting which has become standard throughout the world. Its principal features are very familiar, and yet a mention of them may not be amiss.

Surmounting a heavy pier or column, about half the height of the telescope, is the equatorial head, carrying the polar axis at an angle exactly equal to the latitude of the locality, and consequently exactly parallel to the axis of rotation of the earth. At the upper end of the polar axis, and at right angles to it, are bearings for carrying the declination axis. This axis in turn is rigidly fastened to the telescope tube at right angles to its optical axis. Both the polar and declination axes carry graduated circles, read by vernier or micrometer. By these the position of the star or planet observed is accurately determined; or conversely, by setting the instrument so that the circles will read its predetermined position, the star is found. The fact that the polar axis of the telescope is parallel with the earth's axis of rotation will make it clear to all that the apparent motion of the stars, caused by the diurnal motion of the earth from west to east, will, when a star is being observed, be counteracted by an equal angu-

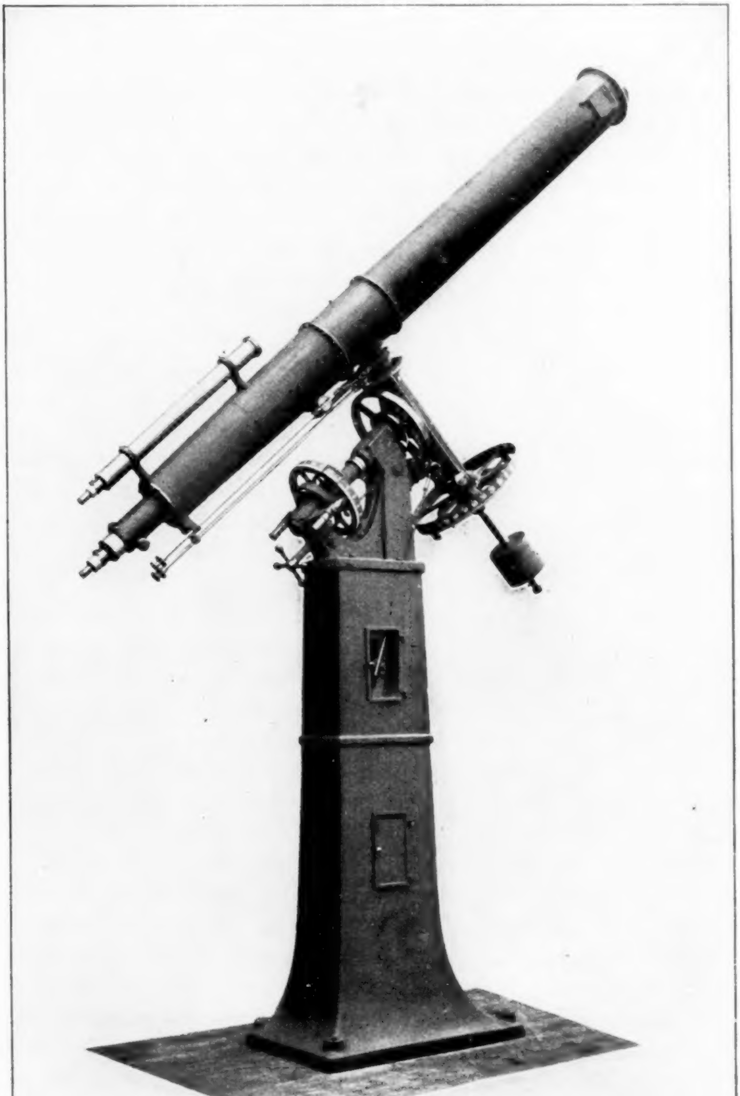

FIG. 5.—DUDLEY OBSERVATORY TWELVE-INCH EQUATORIAL TELESCOPE.

lar revolution of the polar axis from east to west, and the star will therefore appear to stand still in the field of the telescope. This motion of the polar axis was in the earlier equatorial mountings operated by hand, but about the year 1825 driving clocks were introduced to make the tube follow the apparent motion of the star by automatically revolving the polar axis in sidereal time, thus adding greatly to the ease and comfort of the astronomer, and thereby enabling him to make better and more accurate observations.

Not only, however, had the development of the telescope waited for the invention of the driving clock, but also for improvements in the making of object glasses. In this latter respect by far the best results of the early part of this century were obtained by that most eminent physicist, Joseph Fraunhofer of Munich. He died in 1826, but is to-day quoted by the physicists and astronomers of the whole world. His successors, Merz and Mahder, made the largest refracting telescopes of their time, the monuments of their genius being the Harvard College 15-inch telescope, and one of equal size for the Russian National Observatory at Pulkowa, both completed in 1845.

The latter observatory, by the way, was founded by Czar Nicholas II., on the express condition that it should always be equipped with the largest telescope in the world. It has had a brilliant career of usefulness, and is still in the enjoyment of great fame.

With the combination of mechanical and optical efficiency the modern achievements in telescope building became possible. The problems of construction have been studied by many very able minds, and passed through many curious phases, always with a view to helping the astronomer in his practical work. To that end a modern French engineer has devised a form of mounting which is called the equatorial coudé, or elbowed telescope. Remember, if you please, that the temperature of an observatory must be kept as nearly as possible that of the atmosphere outside, otherwise currents of air would make the definition imperfect, and even obscure the lesser stars; and remember, too, that since definition is often best in cold weather, the astronomer must be inured to work in appalling temperatures. Moreover, unless there be an elevating floor to his observatory, he has the added discomfort of putting himself into all sorts of attitudes while observing. It is to obviate these discomforts that the coudé was

designed. Here the polar axis forms part of the tube, the observer looking through the upper end, while sitting comfortably in his warm room, in an attitude as easy as though he were using a microscope. The star being twice reflected before the image is formed in the focus, it is possible to bring all motions under control of the astronomer while seated, if he so please, in his easy chair. The Paris Observatory has two of these instruments, one of 9½ and the other of 24 inches aperture. There is also one at

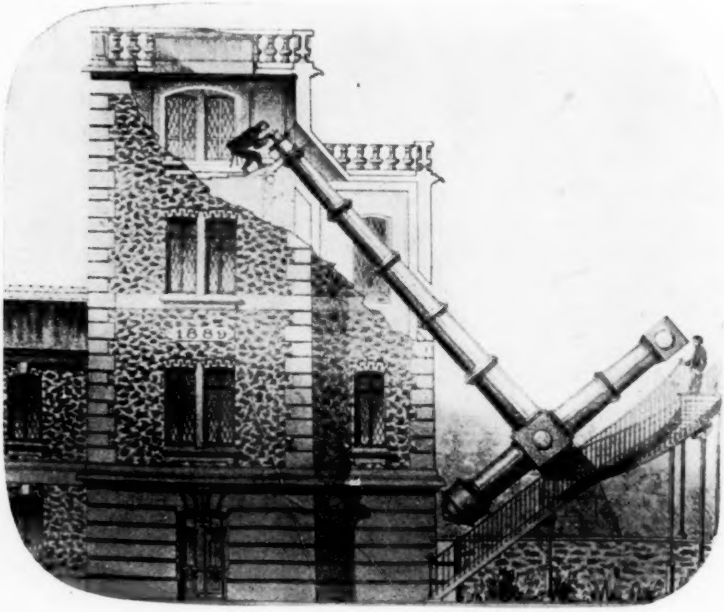

FIG. 6.—EQUATORIAL COUDÉ, PARIS.

Vienna, and the type is gaining more favor than was originally prophesied for it by those who feared loss of light and definition through the use of methods of reflection. Its ingenuity, at least, cannot be questioned.

Again, the combination of optical and mechanical efficiency in the telescope gave an immense impetus to the rise of observatories. The first national observatory was that of Copenhagen, founded in 1656. The Paris Observatory followed in 1667, and Greenwich in 1675. So they came into existence gradually, up to the middle of this century. Since then, who can number them?

The era of large telescopes may be said to date from this same period, 1845, and the race for supremacy has been a rapid one; for during the last fifty years the power of telescopes has been

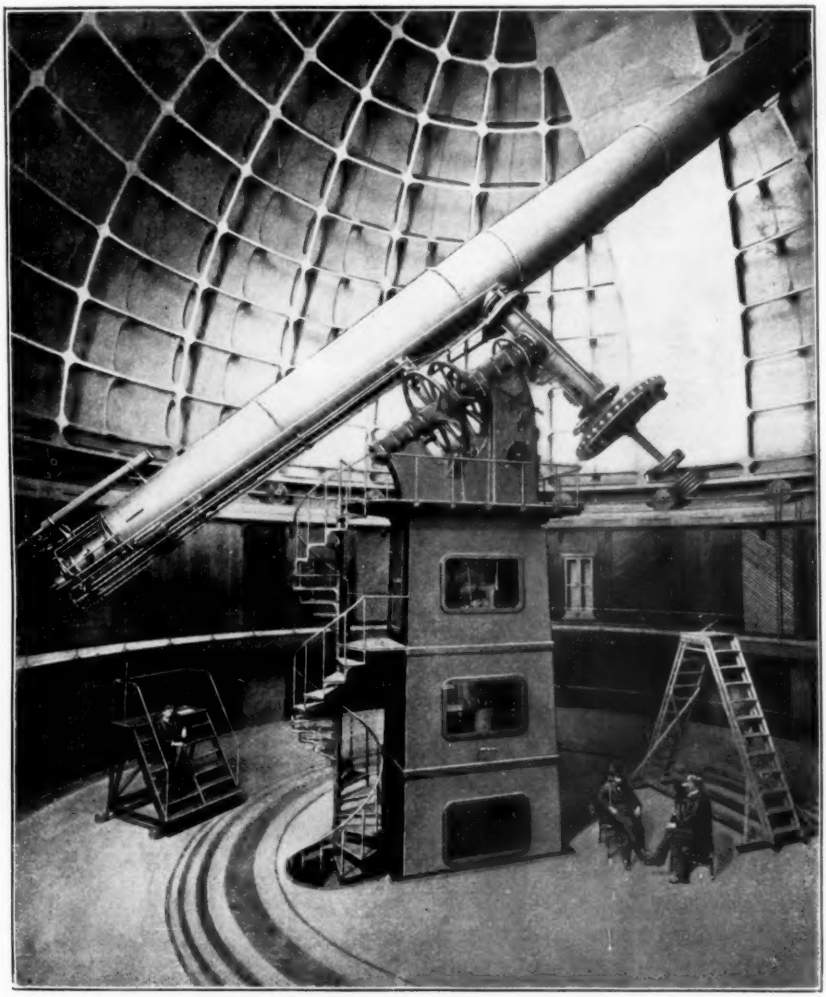

FIG. 7.—LICK OBSERVATORY THIRTY-SIX-INCH TELESCOPE.

increased seven-fold. The superlative degree has been applied, in turn, to the 18-inch telescope of 1861, now at the Northwestern University, and to the 26-inch, made in 1871 for the United

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States Naval Observatory. Next the honor was transferred to Russia, where at Pulkowa, in 1881, a 30-inch telescope was installed. This remained the largest until the 36-inch Lick telescope was completed in 1888. A general impression seemed then to prevail that the limit of size and power had been reached, and that the observatory on Mt. Hamilton would maintain its position as the Supreme Court of Astronomy for a long time. Its supremacy, however, extended over a period of only nine short years; for the present year has witnessed the completion and dedication of the Yerkes Observatory, whose giant equatorial, now the largest, is surely destined long to remain so, unless surpassed by the monster projected for the Paris Exposition of 1900—projected, not completed, for these terms are by no means synonymous in optics.

Not only do the casting and figuring of a great lens demand ability of very high order, but the mounting has passed from the province of the mechanic and instrument-maker to that of the engineer. Consider for a moment this element as found in the 26-inch telescope of the United States Naval Observatory, the 36-inch Lick, and the 40-inch Yerkes telescopes, which, while possessing differences such as rendered the construction of each a matter of independent design, are yet of the same general type. The problems presented to the engineer in designing and constructing such great celestial engines are many and varied. Let us examine a few of them in the case of the Yerkes instrument. The weight of the 40-inch objective, with its cell, is 1,000 pounds. The weight of the entire telescope is 70 tons. The tube alone weighs 6 tons and is 62 feet long. Now the column supporting these heavy movable parts must be rigid in the last degree, and yet of convenient form. To secure these results it is made rectangular in shape, and is cast in four sections, rigidly bolted together. The lower section has a broad, extended base, 14 by 18 feet, anchored in the solidest manner to the masonry foundation. The upper section contains the driving clock and its attendant mechanism, while surmounting this section is the equatorial head, supporting all of the movable parts of the telescope. A spiral staircase on the south side of the column gives easy access to the clock room in the upper section, and also to the balcony surrounding the head.

The great tube must be as free from flexure as possible, and of such form and construction as to insure minimum weight. It is

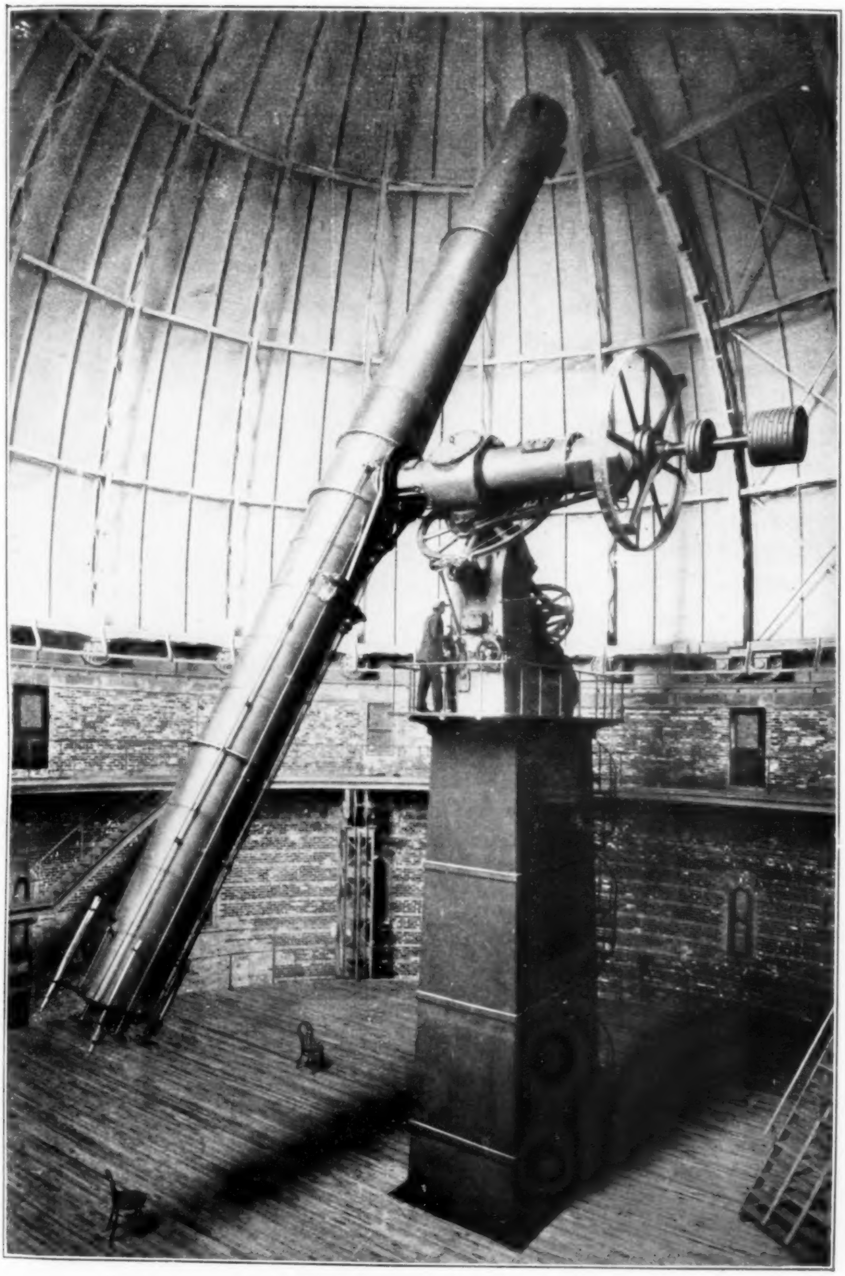


FIG. 8.—YERKES OBSERVATORY FORTY-INCH TELESCOPE.

made of steel in five sections, the central section being so designed as that the declination axis may be accurately and rigidly fastened to it. The objective end terminates in a flange so arranged as to carry the great objective and allow proper adjustment. At the "eye end" provision is made to carry not only the micrometer and eyepieces, but a spectroscope and spectro-heliograph and other physical and astro-physical apparatus. At the eye end, too, the observer must have in reach the hand clamps and slow motions in declination and right ascension, as well as the buttons operating the electric clamps and slow motions (Fig. 9). The polar and declination axes—by means of which the telescope can be directed to any part of the visible heavens—must, like the tube, be as free from flexure as possible. They are hollow, to allow a part of the complicated mechanism to be carried through them. All bearings for these axes must be made with the greatest accuracy, and have the friction reduced to a minimum, for the movements of the tube and its attendant mechanism must be as free as possible. The weight of the tube, the axes, and their connections, all of which must move when the telescope is following the apparent motion of a star, is no less than 22 tons.

Provision must be made for conveniently pointing this monster "optic tube" to any part of the visible heavens. This is roughly and quickly done by the electric motors, one giving the motion in declination and the other in right ascension. Two smaller motors are also provided for giving slow motions in both directions. By the aid of these motors the astronomer is able to bring the star to the centre of the field, in coincidence with the micrometer wire. These movements must also be easily made by hand, either by the assistant on the balcony or by the astronomer at the eyepiece.

The driving clock, which is located in the upper section, must be able to carry all this great weight in exact sidereal time, so that the star shall appear to stand still as it is bisected by the spider web of the micrometer in the focus of the telescope. The propelling power is obtained by a weight of 850 pounds, which, when the clock is in motion, falls $1\frac{1}{2}$ feet per minute. The mechanism is controlled by a double conical pendulum so mounted as to make one revolution per second, whether it is carrying the telescope or not. The whole mechanism of the driving clock must be so designed that its motion may be instantaneously communicated to the polar axis by electric clamps and also by hand, and that it

shall provide for conveniently changing the speed from stellar to lunar and to solar rates.

Finally, since the success of many important observations de-

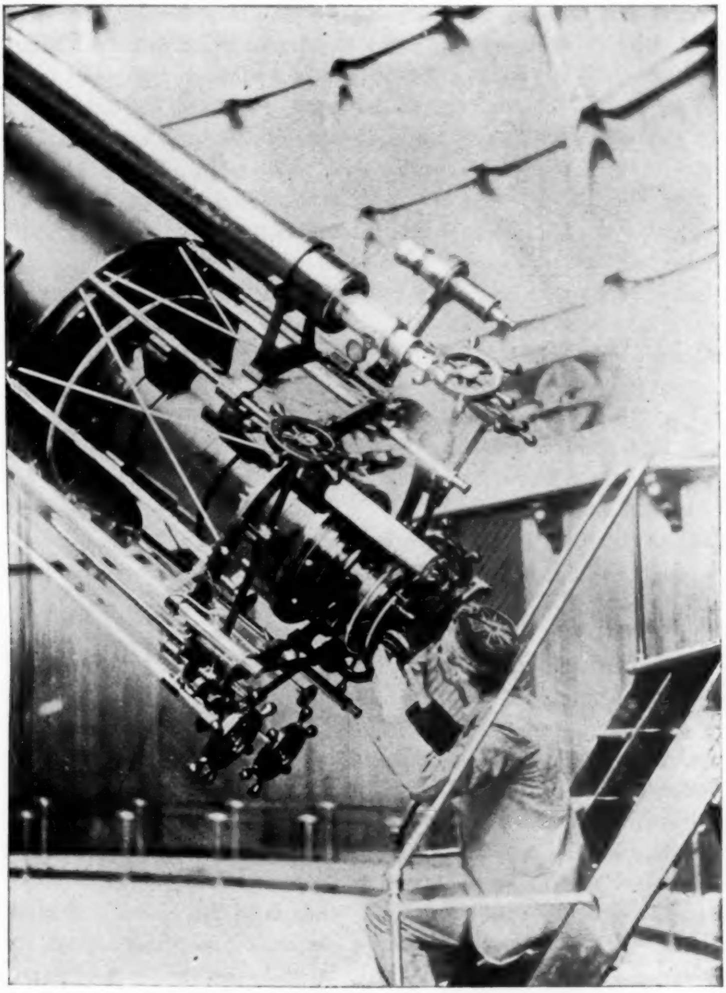


FIG. 9.—EYE END, LICK TELESCOPE.

pends on the constant and regular motion of the driving clock, an electric motor must be introduced for automatically keeping it wound.

Such are some of the provisions made for the convenience of the astronomer in handling a large instrument. The mechanism is of necessity complicated, and, as has been said, belongs distinctly to the sphere of engineering.

There is a popular idea that objectives are made large in order to magnify enormously, whereas the purpose is rather to secure more light. The pupil of the eye has a diameter of only about $\frac{1}{5}$ of an inch. The telescope serves to increase the number of rays that can be brought upon the retina, making them as many as fall on the surface of the objective. The retina is thus virtually increased in the ratio of the square of the diameter of the objective to the square of $\frac{1}{5}$ of an inch. Thus, with a 2-inch aperture, the number of rays collected is 100 times as great as the number collected by the naked eye. Figuring thus, too, the star seen through the Yerkes telescope is more than 40,000 times as bright as when seen with the unaided eye. This is the true and unanswerable argument in favor of large telescopes. In our country, where exist the largest, the science of astronomy is in a state of progress which may well be a source of pride. It was the 26-inch telescope of our Naval Observatory which first showed the satellites of Mars, and the 36-inch Lick glass that first revealed the fifth satellite of Jupiter. Sensational discoveries are reserved for large instruments, and one such may yet reveal to us the trans-Neptunian planet so long and vainly sought in our own day.

The original use of the telescope was to study the motions of heavenly bodies, but it was the elder Herschel who first proposed to himself to make of it a means of determining, as he expresses it, "the present constitution and the evolution history of the stars, the comets, the sun, the planets." Thus he became the founder of the science of astro-physics. Many observatories to-day confine their activities to this form of research. To mere observing have been added photography, photometry, spectroscopy, and so, in process of time, the telescope has passed through a form of evolution that allies it to the history of civilization. While astronomy, as we know, is, of all sciences, the one most removed from the sphere of commercial results, yet the telescope, in some form or another, is the one and only means we have of navigating ships, of measuring wide expanses of territory, of determining latitude and longitude, and of keeping time. Every navigator who sails out of sight of land must have a fair knowledge of astronomy. His compass tells him approximately

the cardinal points, but it gives him no hint as to where on the broad ocean he is. Every ship, therefore, that crosses the ocean goes out equipped not only with optical instruments for taking the altitude of the heavenly bodies, but with a nautical almanac containing the exact position for each day of the sun, moon, planets, and fundamental stars; so that by careful observation and simple computation the navigator can closely determine his latitude and longitude.

Government observatories keep their corps of eminent astrono-

FIG. 10.—LICK OBSERVATORY, MOUNT HAMILTON, CAL.

mers ceaselessly at work making and reducing observations for the use of navigators who are supplied with these nautical almanacs indicating the position of the heavenly bodies for several years ahead.

The telescope is just as indispensable, too, to the surveyor. In laying out a railroad across the continent his position is found by observing his latitude and longitude. The distance from New York to San Francisco has never been closely measured, but the engineer has accurately determined it by comparing his observations made at the two places. It is practically impossible to measure the distance between New York and Liverpool, but very

easy to determine it within a few hundred feet by the aid of the telescope. Rivers and mountain ranges are often taken as dividing lines between countries; but where these natural lines are not diplomatically located, the telescope is brought into requisition, and imaginary lines, designated by degrees and minutes of latitude or longitude, form the divisions sought.

Again, the telescope with its attached camera now does in forty minutes what it formerly took an able astronomer four years to accomplish, and does it better, mapping stars he never saw, and making a permanent record with no discounts for the personal equation. In this connection it is of interest to recall the fact

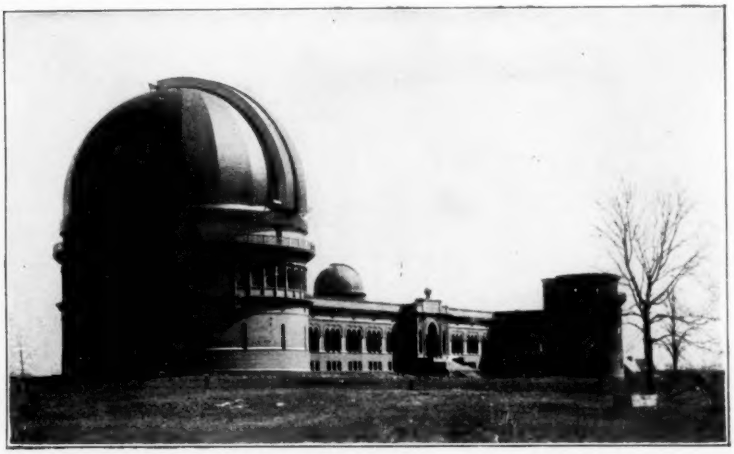


FIG. 11.—YERKES OBSERVATORY, GENEVA LAKE, WIS. LARGE DOME NINETY FEET DIAMETER.

that the first heavenly body ever photographed was the moon, in 1840, a feat accomplished by Dr. J. W. Draper in our own country. In 1845 the sun was first photographed, in Paris; in 1850, at the Harvard Observatory, the first star was photographed. In these days photography makes all the star-maps, and keeps its own records intact, a magnificent legacy from this to future generations.

Substitute for the camera the spectroscope, and equally marvellous results follow. The instrument is then called a telespectroscope. While Wallaston, as early as 1802, knew of the existence of dark lines in the spectrum of the sun, and Fraunhofer, in 1823, saw them in the spectrum of the stars, neither of these

investigators recognized their cause. It was not until the years 1859 and 1860 that Bunsen and Kirchoff published their researches which gave to the scientific world the meaning of the dark lines seen crossing the spectrum of the sun, stars, and other heavenly bodies. From this date the spectroscope, when attached to the telescope, became one of the most powerful instruments in the hands of the astronomer, as it enabled him to determine the

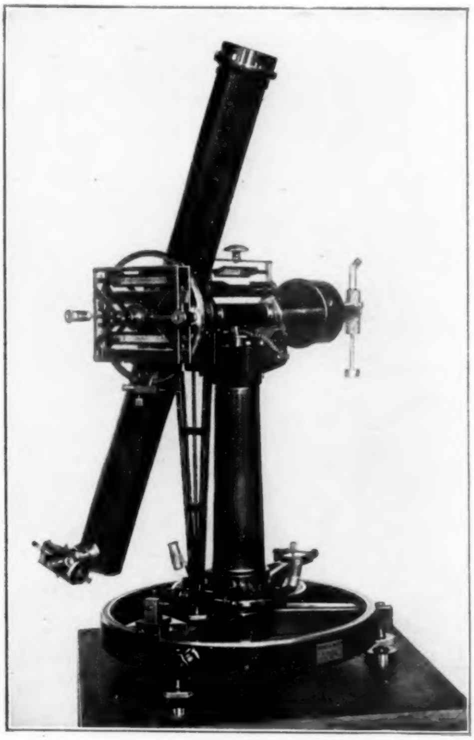


Fig. 12.—Zenith Telescope.

constitution of the heavenly bodies, to measure their motion in the line of sight, to watch the solar flames as they burst forth from the sun, and, in very recent years, to photograph these interesting phenomena, as well as faculæ that cannot be seen with the telescope.

The spectrum lines due to solar prominences had never been seen without a total eclipse, until Janssen found, just after the

eclipse of 1868, they could, by a proper arrangement of his spectroscope, be seen at any time the sun was shining. Lockyer had really predicted this discovery in 1866. This opened up a new field in solar research, for it was soon found that the form of the solar prominences could be built up from varying lengths of the spectrum lines. On the 13th of February, 1869, Dr. Huggins, of London, saw and sketched the first prominence in bright sunlight.

FIG. 13.—PRIVATE OBSERVATORY, CLEVELAND, O.

Lockyer, in England, and Zollner, in Germany, by an improvement in Huggins' method made it so easy to observe solar prominences with the spectroscope, that maps are now daily made of the sun's atmosphere.

The spectroscope was soon found to be invaluable for the study of the various types of stars, for observations of new or temporary stars, for determining the motion of stars and nebulæ in the

line of sight, and for a critical study of the sun's rotation period. In the hands of Keeler it has solved the mystery of Saturn's rings. Hale and Deslandres have photographed the solar faculæ and flames, and astronomers all over the world are now working on problems intimately associated with the physical constitution of the heavenly bodies, that must sooner or later give up their secrets to this all-powerful instrument.

So it is clear that the instrument which began its course as a military spy-glass, and which to-day regulates our clocks and schedules the running of our railroad trains, is the same telescope of which it is written, in the glorious records of history, that it spanned infinities of space, wrought a revolution in human thinking, and called a new universe into being.

[*Note by the Publication Committee.*—This paper was presented at an evening session of the Society, and was copiously illustrated by wisely selected views thrown on the screen by a projective lantern. The illustrations of the printed paper are from reproductions of a few of these views.]

DISCUSSION.

OPTICAL GLASS.

Mr. Jno. A. Brashear.—A few weeks ago our President asked me to write some notes on the evolution of the manufacture of optical glass as a supplement to his paper on the "Evolution of the Telescope," the two subjects being so intimately associated that it might be of interest to the Society to have some information upon this phase of the subject. I have endeavored to carry out his wishes in this paper.

It is difficult indeed to trace the history of optical glass in its earlier development. I have studied almost every available authority on the subject, and have concluded that no great weight can be placed upon many of the earlier stories told us. Mollineux, in his *Dioptrica Nova*, written in 1690, says, "that the ancients had no knowledge of optical glasses is most evident from their universal silence in this matter; their most learned and inquisitive philosophers making no mention or at least hint thereof in their writings, and doubtless a contrivance of such universal use, beneficial to all old men, both in reading and writing, could not have been so concealed as that the least footsteps thereof should remain to posterity. The only relief they had for

their decayed sights were certain colyria, or eye salves, and when they failed them they were left alone in the dark for minute and close objects." Pauciollus, in his *Rebus Inventio*, quotes this passage from Plautus' *Cedo Vitrium*, "necesse est conspicillis uti" (literally, something to see with), which, he says, cannot possibly mean anything else but the glasses in all spectacles; but Mollineux plainly states that such a passage is not to be found in Plautus.

In an Italian work published but five years before the remarkable work to which I have referred (Mollineux), there is a statement that spectacles were invented about the year 1150, but this date is probably too early. It is, however, quite certain that the date of the discovery of lenses, as applied to spectacles, is somewhere between 1280 and 1311.

In a manuscript written in 1299, preserved in an Italian library, there is a sentence which, translated into English, reads thus: "I find myself so pressed by age that I can neither read nor write without those glasses they call spectacles, lately invented; to the great advantage of poor old men when their sight grows weak."

Friar Jordan, in a book of sermons printed in 1305, tells his audience that "it is not twenty years since the art of making spectacles was found out, and is indeed one of the best and most necessary inventions in the world."

From this and much other data it is quite certain that spectacles were known in the latter part of the thirteenth century.

Mollineux says that "there is no positive knowledge of who was the happy man that first hit upon this lucky thought. 'Tis true, indeed, if we credit the forementioned chronicle of the convent at Pisa, Friar Spina makes as fair a challenge to the invention as the first author who refused to communicate it. But I am apt to believe that whoever this close man was that would not impart to Spina, he was a friar, and that these monkish men, and Jordan among the rest, had this invention whispered among themselves before it was public, and that they all had the first hint from our countryman, Friar Roger Bacon."

After a great deal of research I have failed to find any satisfactory data as to the character of the glass used in making spectacle lenses. That it was crown glass there seems little doubt, for the reason that all flint glass made during this period was very impure; indeed, up to the beginning of the present century no flint

glass had been produced which was of any value for optical purposes.

It is entirely foreign to the purpose of this paper to trace the history of glass-making, outside of its association with the development of optical instruments, interesting as this part of the subject may be ; but when we consider that the manufacture of glass extends far back into the past, perhaps forty centuries, it is rather surprising that we have so little information as to the kind of glass used in the manufacture of spectacle and other forms of lenses, such as those used in the earlier telescopes. It is quite certain that window glass was made in the thirteenth century, and mirror glass was made in Venice as early as 1317, but glass mirrors did not displace steel mirrors, as they were made up to the sixteenth century, when the art of silvering mirrors was perfected, although processes of silvering had been known for four hundred years.

As the making of window and mirror glass was contemporaneous with the invention of spectacles, there remains little doubt in my mind that the crown glass, from which lenses were made, was selected from the window or mirror glass used at that time, and this same method of obtaining glass for spectacles and other lenses must have been followed for more than three centuries.

Through the courtesy of Admiral Mouchez, Director of the Paris Observatory, I was permitted, in 1892, to examine some of the largest objectives made by Divini, of Rome, and Campani, of Bologna, about the middle of the seventeenth century, one of which was 6 inches diameter. I am quite sure that the material out of which these lenses were constructed is similar to the mirror glass manufactured at the time they were made. If my memory serves me right, the 6-inch lens was not over $\frac{1}{4}$ of an inch in thickness. I well remember examining the object glass used by Cassini, with which he discovered the double ring of Saturn. It was about $4\frac{1}{2}$ inches in diameter, and not over $\frac{3}{16}$ thick at the edge, and as the radius of curvature was, I should say, not less than 40 feet, the lens was very little thicker in the centre than at the edge. Owing to the many little scratches on the surface of this historic glass, I was not able to determine the character of the material in it, but it must have been of fairly good quality, or Cassini could not have made such discoveries with it.

A new era in telescope-making dawned upon the world when Dollond made his wonderful discovery of correcting the chromatic

aberration of the object glass, mention of which has been made in the address of our President.

But Dollond's discovery required the use of both crown and flint glass. Crown glass of fairly good size could be procured by a careful selection of the best grades of plate glass, but flint glass of sufficient purity could not be obtained for objectives of more than three to three and a half inches diameter, and then only by chance could pieces be found by searching through a large mass of material at the glass works. So serious did the problem become that the Academy of Sciences at Paris offered a prize to the successful maker of flint glass for optical purposes. Macquer, a celebrated chemist; Roux, of the great St. Gobain glass works; Albert, of the Langress glass factory, all tried to solve the problem, but failed completely, and it is stated by Bontemps, one of the best authorities on the manufacture of glass, that out of a hundred pounds of the best flint glass any of the makers could produce, they were often unable to get the material for an objective of 3 inches diameter, and at this period—about 1811—a piece of good flint glass $3\frac{3}{4}$ inches diameter, free from imperfections, was considered of great value.

In an old and very rare book by Dr. Kitchiner, I find the following note: "I am informed by the Messrs. Dollonds that between the years 1760 and 1765 they met with a pot of uncommonly fine flint glass: Crown glass was also then to be had of much superior quality than they had been able to procure since the cessation of the glass house of Ratcliffe—however, they found that they could not even then with these confessedly superior materials produce an object glass of larger aperture than $3\frac{3}{4}$ inches. Such was the case then when it was much more plentiful than it is now." This note written in 1818 shows that it was a mere chance melting of glass which gave the Dollonds their opportunity to make lenses of so large an aperture as $3\frac{3}{4}$ inches.

When Peter Dollond made a triple lens object glass of $3\frac{3}{4}$ inches aperture for Dr. Kitchiner, so great was his interest in it that he remarked to Kitchiner, "Yes, that object glass is one of the things that is to make me immortal."

Bontemps is authority for the statement that M. D'Artigues, one of the best makers of crystal glass in France, gave his undivided attention to the production of optical flint glass, but after many trials succeeded only in producing, probably by mere chance, a few pieces, one of which was good enough to make a

lens of 4 inches diameter. An objective was made from this large (?) piece of glass by M. Cauchoix and presented to the class of physical and mathematical sciences at the Institute of France by M. D'Artigues.

M. Biot made a report of M. D'Artigues' method, which, while it gave in detail the various steps of the process, proved very unsatisfactory, for, summing it up, Bontemps puts it thus: "Make a pot of good flint glass with all possible care by M. D'Artigues' method and you will find in it *some glass* for optical purposes."

In Biot's report he made mention of the fact that "there was still fine striæ left in the glass made by M. D'Artigues,—that there was not enough to do any harm,—but which he would ask him to remove if possible in order to obtain the best objectives."

But the time had come when, with the want, came a man to supply it; and, like many of the most valuable inventions which have opened new eras in the world's history, this one came from where it was little expected. Pierre Guinand, a watchmaker of Brenets, near Neuchâtel, in Switzerland, had learned of the difficulty of making flint glass, and, although he had no knowledge of the processes employed, ignorant in a great measure of the laws of physics and chemistry, he attacked the problem in a variety of ways, each time gaining knowledge which was invaluable to him. He seemed to be endowed with the spirit of research, coupled with great perseverance and patience, and, although he worked years without results, success finally came to him.

There are two serious difficulties in making flint glass; one is that of a tendency of the oxide of lead—which is one of the important constituents of this glass—to fall to the bottom of the pot or crucible when it is in a state of fusion. This tendency of the lead oxide to sink produces unequal density in the various horizontal layers of the glass, which in itself would not be so important if it were possible to cut truly horizontal sections from the cooled mass; but this is, in the very nature of the case, an impossibility, for, in cooling, the glass breaks up into more or less irregular shapes, and from these pieces must be selected the material for lenses.

Another and most serious difficulty is to get rid of striæ or cords in the glass, which requires a very perfect mixture of the fluid mass, but which is rarely ever attained.

Guinand's process is essentially as follows: A single pot or crucible, made of very pure clay, with an opening in the side near

the top, is placed in a furnace especially arranged so that the heat can be applied all around it and as equally as possible. The material for the glass is placed in the pot or crucible in two or three charges, separated by an interval sufficient to allow the previous charge to settle. The material, or batch, as it is technically called, is now thoroughly melted, requiring about thirty hours for perfect fusion, a very high temperature being required. Tests are taken from the melted material from time to time until the test pieces show not only perfect fusion, but the greatest possible freedom from air bubbles. At this stage of the process Guinand's invention is brought into requisition; namely, a thorough stirring of the fluid mass. For this purpose a stirrer, made of the purest clay, is introduced into the pot, having been previously brought to quite a high temperature so as not to chill the glass. This stirrer, called a "Guinand," is so made that an iron handle can be secured inside of the upper end of it, the long handle of the iron part being carried in a sheave on the side of the furnace so as to carry its weight.

The process of stirring is now commenced, and is a most laborious task, not only on account of the character of the work, but of the excessive temperature which must be endured by the workmen.

Two men are required to do this work, as it must be kept up for about three hours, or until the mass has become so stiff that the stirrer can no longer be moved by the operators. M. Feil told the writer some years ago that this process of stirring is most exhausting in its nature, and that few men can stand it. The temperature is allowed to fall during this and subsequent stirrings, so that the metal may approach so nearly to the solid state that the metallic oxides will not sink. For the commoner grades of optical flint glass one stirring is usually considered sufficient, but for the best grades the temperature is raised after the first stirring, and a second and sometimes a third stirring are found necessary to work all the remaining air bubbles to the top, as well as to mix up the mass so thoroughly that it will be of as nearly as possible the same density from top to bottom. So difficult is it to move the stirrer toward the end of the process that the "Guinand," or clay stirrer, cannot be moved around the pot in less than six to seven seconds. No doubt mechanical methods could be devised for this part of the work. The iron handles of the stirrer must be frequently changed on account of becoming so hot as to form scales of gray oxide, which, if they should fall

into the glass, would ruin it for optical purposes. One of the great difficulties the optical glass maker has to contend with is the presence of iron in the clay from which the pots or crucibles are made.

After the final stirring has been completed, double covers are placed over the mouth of the pot and carefully luted with clay. Every avenue for the ingress or egress of air in the furnace is carefully sealed, and the furnace, pot, and glass allowed to cool during a period of six to ten days, according to the weight of the melted mass and size of the furnace.

The front of the furnace is now taken down and the crucible drawn out in order to get at its contents. The pot is usually found pretty well shattered, and is broken away from the now solidified and cooled mass within it. The glass is also found broken into irregular lumps of greater or less size, but all are carefully examined and set aside for use according to their value.

Just here comes in the second process, discovered by Guinand, a process invaluable in the art of optical glass making, and which is used to-day almost exactly as it was in the days of its illustrious discoverer or inventor.

Let us suppose a lump of this glass is selected which has weight enough to make a disk twelve inches diameter. It is first ground and polished in places which will allow of a careful inspection of the interior of the mass. It is rare that a lump of such size is free from imperfections, some of which may be in the very centre of the piece chosen. A careful diagnosis having been made, the impurities are ground or cut out by various methods, and after all defects which can be reached have been eliminated, the lump is ready for the third stage, namely, that of softening it down to a disk of the proper diameter and thickness.

In this work the most scrupulous care is necessary, for if the lump be as pure as crystal quartz and does not go through this third stage as it should, it will be useless for the purpose of making a fine object glass.

A special furnace is constructed which is called the "annealing oven," in the centre of which a mould is placed of the size necessary to make the required disk. This mould is of clay, which for disks of large size is so made that the ring which forms the thickness is separated from the flat bottom. The ring is also made in two pieces and secured by a wire wrapped around a groove on the outside, so that the annealed disk may be easily taken from

the mould when it becomes cold. To prevent the disk from sticking to any part of the mould, it is first painted over with mucilage and then dusted with pulverized chalk.

The lump of glass is now laid in the mould, and a cover of clay is placed over it and the glass so that no flame can strike it directly. The temperature must be raised very slowly, so that the lump of glass will not crack, for if once cracked it is ruined. It may be of interest to know that a lump of glass may be sawed or cut almost in twain and, if placed rightly in the mould, make a perfect disk, as when softened by heat the part which has the cut in it will slowly float to the top, solid glass taking its place; but if the cut extends through the lump, it coalesces without rising, making the disk useless. The temperature of the annealing oven need never be any greater than the melting point of glass, which of course varies with the different kinds of flint and crown. The muffle, or cover, which is placed over the mould is so made that it may be removed at any time by an iron fork, through a small opening in the furnace, so as to examine the glass.

It is necessary that the temperature should be kept quite constant until the glass has become evenly heated throughout, and until all depressions have arisen to a common level. It is almost imperative that the sides of the annealing oven should be so constructed in relation to the mould that the cooling shall be symmetrical, else the disk will be certain to show the effect of irregularity of cooling. It has been found that in annealing glass the temperature may be brought down rapidly, without any danger, until it reaches a certain critical point, which I believe has not been accurately determined, but which, from some experimental data, I am inclined to think is not far from the point of incandescence, about 997 degrees Fahrenheit, or 523 centigrade.

Before this critical point is reached the annealing furnace must be rigorously closed to all intrusion of air, and as for large disks the furnaces are quite massive, the process of cooling goes on very slowly, allowing the molecules of the glass to find their normal positions, or, as it has been very prettily stated, "to lie kindly in their relations with one another." The cooling process is necessarily very slow, and for large disks requires from ten to twenty days. Smaller disks and plates require less time. For forming and annealing small disks and plates, the inner edges of the moulds are bevelled to allow the annealed glass to drop out readily after it has become cold.

After the first annealing the disk is ground and polished on the faces, again examined for imperfections and the quality of the annealing. If imperfections such as striæ, cords, or stones are found in the glass they must be ground out and the disk must again go through the same process. A second or third annealing is fraught with new dangers, the principal one of which is that of devitrification, *i.e.*, changing of the glass from the transparent to the translucent or opaque condition, thus making it useless for any purpose whatever. The writer has seen a beautiful thirty-inch disk ruined in this way, but, fortunately, devitrification rarely happens with the careful workman.

These processes as worked out by Guinand are practically the same as those used to-day. Some improvements have been made by Feil and Mantois of Paris, who have made the magnificent disks of all the larger objectives made in recent years. Dr. Schott & Co. of Jena have also added some features to the annealing process, which have yielded splendid results so far as freedom from molecular strain is concerned. Since the days of Pierre Guinand many new kinds of glass have been discovered and made by the French and German glass makers, some of which have proven to be of the highest value to the optician. To Dr. Schott, Dr. Abbe, and Dr. Zeiss in Germany, M. Feil and Mantois in France we owe a debt of gratitude for their invaluable services in this important work.

But our disk has not yet passed through the entire gauntlet which it must run before being pronounced fit for a great objective. All disks are sent to the optician with a guarantee of their perfection. This "doubting Thomas" now repolishes the surfaces and with his polariscope examines the glass for strain. If the annealing has not been regular, the tell-tale polariscope has no mercy, but picks out the defects with unerring certainty. Should it pass this ordeal, it must then be subject to a careful study for striæ and unequal density. To locate striæ, if they exist, a beam of light is concentrated by a lens on the various portions of the disk, every inch of which is carefully studied; the keen eye of the observer rarely failing to detect any striæ or cords that would do harm. Unequal density is a far more difficult thing to detect, and unless it is of a pronounced character (something unusual in the present state of optical glass making), it cannot be detected until the objective has passed the stage of grinding and polishing.

If the density is but slightly different in the various areas of

the glass, it may be corrected by a system of local retouches well known to the practical optician; but if there is a marked difference in the density, the disk must be condemned and returned to the manufacturer, as it is useless to undertake to make a good objective from it.

Although this paper has grown much longer than intended, I must "retrospect" in order to make the history complete.

After Guinand had practically perfected his discoveries, he formed a partnership with M. Utzschneider of Munich, the firm being also joined by the celebrated Fraunhofer. They established a factory at Benedictburn, where many disks up to 6 and 7 inches diameter were made. At this factory the 9-inch disks for the Dorpat telescopes were also successfully cast, which at that time were considered marvels of skill in optical glass making.

About this time Guinand sent a 6-inch flint disk to England, which was examined by a committee of savants, and pronounced very perfect. Steps were taken to investigate the subject, and Faraday made some very interesting experiments; but with the exception of producing a variety of flint glass of very great density, this illustrious man did not add very much to our knowledge of optical glass. It was not until about the year 1848 that optical glass was made in England, and then its manufacture was established by M. Bontemps, who had learned the secret from the son of Guinand.

After Guinand had left Bavaria and returned to his native mountains, Utzschneider and Mertz continued the work at the old factory, where they produced the disks for the 15-inch telescopes of Pulkowa and Harvard College Observatories. Guinand, having returned to Switzerland, started a factory of his own. After his death the work was carried on by his widow and younger son, who were in turn succeeded by M. Daguet, who made some excellent glass for optical purposes. In 1827 M. Bontemps, having formed a partnership with the elder son of Guinand, started a factory at Choisy-le-Roi, where, in 1828, he produced disks from 6 to 12 inches diameter. From this time Bontemps and Guinand commenced the manufacture of optical glass as a settled business; and as they were much encouraged by the scientific societies of France, they not only produced flint glass of the finest quality, but excellent crown glass, for which they received the grand prize in 1840.

The elder Guinand died in 1823. His son, the associate of

Bontemps, died in 1851, and was succeeded by M. Feil, who made the disks for many of the larger telescopes of modern times, including those for the great Lick objective. At the death of M. Feil, M. Mantois became his successor.

M. Mantois has had most wonderful success in making glass for objectives of the largest size; for not only did he successfully cast the 42-inch disks for the Yerkes telescope objective, but has recently succeeded in making a pair of 45-inch disks for the great telescope to be constructed by M. Gautier for the Paris Exposition of 1900.

In 1881 Doctors Schott and Abbe made a critical study of the chemical and physical principles involved in the manufacture of optical glass, a study which has proven invaluable in developing modern optical instruments. It was a wise policy which prompted the Prussian Government to assist these scientific investigators in this important research; indeed, their discoveries have been epoch-making in the history of the manufacture of optical glass. In 1885 a factory was started in Jena which has turned out a large amount of splendid material, many new kinds of glass having been placed within the reach of the optician.

In the year 1848 M. Bontemps was induced to leave France and commence the manufacture of optical glass with Messrs. Chance, in Birmingham, England. Since that time this firm has turned out many large and fine disks for objectives, a pair having been completed in 1855, measuring 29 inches in diameter.

Attempts have been made to manufacture optical glass in this country with quite flattering success. The first experiments were made by the Lenox (Mass.) Glass Manufacturing Company twenty years ago, but so far as the writer is aware they never turned out any good glass. About four years ago Messrs. Macbeth & Co. established an optical glass factory in connection with their large works at Elwood, Ind., where they had abundance of natural gas for fuel. Mr. Feil, son of the celebrated French optical glass maker, was engaged by Mr. Macbeth to superintend the work. After many costly experiments and many discouragements this firm succeeded in making some beautiful glass of great purity and remarkably fine quality of annealing. The 12-inch disk for the photographic correcting lens of the Dudley Observatory was made from glass furnished by this firm, and a large number of smaller disks have also been worked from it by American opticians, for various institutions of learning. Mr. Macbeth has also

succeeded in making a pair of crown and flint disks, 23 inches diameter, of very great excellence. Surely we have the material, the fuel, and the skill in this country to make optical glass as well as the finished objectives for all our astronomical instruments.

Lengthy as this paper has become, I confess I have only skimmed over the subject, passing by much which might be of interest, much which would make it of greater value as a paper of reference; but the theme in itself is too great to be treated as it should in a paper like this; for when we consider that it is through this self-same "optic glass" we have learned the marvellous "story of the universe," the *complete* story is certainly worthy of a place in our annals.

> "Go to yon tower, where busy science plies
> Her vast antennæ, feeling thro' the skies;
> That little vernier, on whose slender lines
> The midnight taper trembles as it shines,
> A silent index, tracks the planets' march
> In all their wanderings thro' the ethereal arch,
> Tells through the mist where dazzled Mercury burns,
> And marks the spot where Uranus returns."

DCCLI.*

A CONVENIENT FORM OF WIRE-TESTING MACHINE

BY ARTHUR L. RICE, BROOKLYN, N. Y.
(Junior Member of the Society.)

THE use of a small and inexpensive testing machine is often desirable for the purpose of illustrating the action of the various metals under stress, or for the testing of wire and small specimens and for the testing of small cast-iron samples in the foundry to determine the quality of the iron used.

A description of such a machine which has been in use by the writer for the past year may be interesting to the Society.

To be available, the machine must be convenient to handle and read, must have sufficient strength, must record the breaking load, and must have little or no shock at breaking. Above all, it must be cheap to build.

The resulting machine is shown in Fig. 14. The spring-balance dial and hand wheel are convenient to each other, and the machine is mounted at such a height from the floor as to make the scale easily readable. The details of the pulling-gear construction are shown in Fig. 15. The spring balance with a recording hand seemed the most convenient and available method of measuring the load; to avoid the rebound of the balance, an air dash-pot was introduced and has worked satisfactorily. The details of the dash-pot and pulling clamps are shown in Fig. 16. On account of the cup-shaped washer the leather on the dash-pot piston can be made so loose a fit that the piston will drop of its own weight, thus eliminating all error from friction. A small outlet with cover is provided at the top of the dash-pot, so that the amount of the cushioning can be regulated as needed. The pulling clamps are along the lines of the ordinary designs for small machines.

For bending tests a yoke is arranged as shown in Fig. 17, and

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

Fig. 17. Fig. 14.

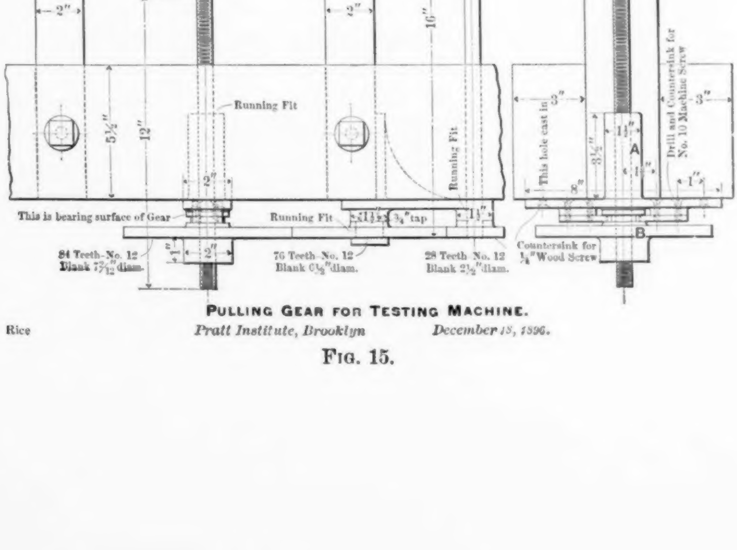


Fig. 15.

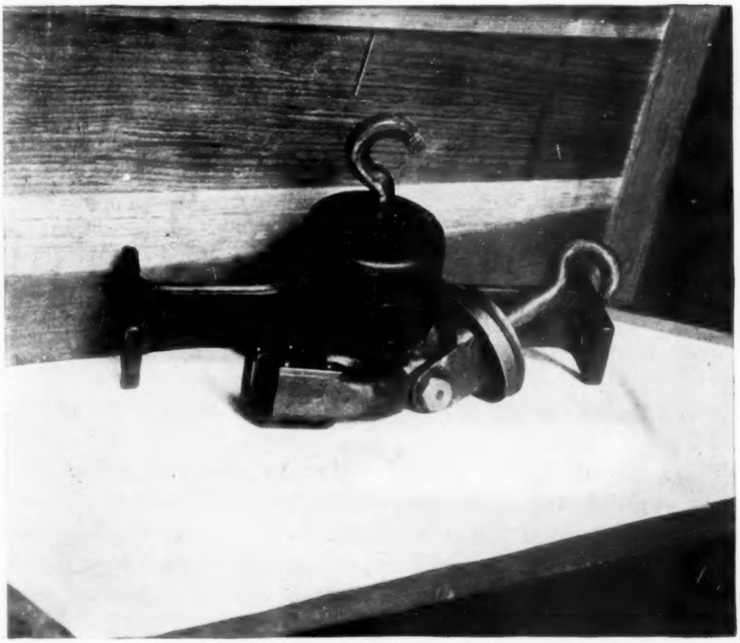


FIG. 16.

the lower grip head is changed for a knife edge; specimens can be tested either as cantilevers, by clamping one end fast to the beam of the yoke, or with a support at each end.

The machine has given excellent satisfaction, is convenient to handle, and works well up to its full capacity, 200 pounds. The cost of twelve machines complete was only about $380, or $31.75 apiece.

DCCLII.*

A BOILER SETTING.

G. W. BISSELL, AMES, IOWA.
(Member of the Society.)

THE sketch presented herewith (Fig. 18) shows a method used by the writer about two years ago for supporting a horizontal return tubular boiler, fifty-four inches in diameter by sixteen feet long.

Two pairs of lugs of special design are attached to the sides of the shell above the fire, and at a distance, to centres, of three feet six inches from the ends of the shell. These lugs rest on hangers of one-inch round iron, which are carried by nuts on wrought-iron saddles cut from three-by-one-inch flat bar iron. These saddles rest on I-beams. At the front end of the boiler one seven-inch beam is used. At the back end the saddles are supported by an eight-inch equalizing I-beam five feet long, which rests on a one-inch roller which has a bearing on a nine-inch I-beam. The latter, and also the seven-inch I-beam at the front end, rest on pairs of columns for which six-inch channel beams are used. Suitable castings serve as sole-plates for the I-beams and as caps for the columns.

Cast-iron plates twelve-by-twelve by one and one-half inches serve as foot plates for the columns.

These plates are set perfectly level on piers of brick-work about two feet square, built independently of the boiler setting proper.

Tie-rods of three-quarter-inch round iron hold the columns to place at the top. Longitudinal stability is afforded by setting the channels into the brick-work of the boiler setting, so that the flanges do not project, but are flush with the wall.

It is thought that the following advantages are possessed by this design over others in more general use :

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX of the *Transactions*.

First. Three-point support for the boiler, by which it is freed from strains due to settling of the columns or setting.

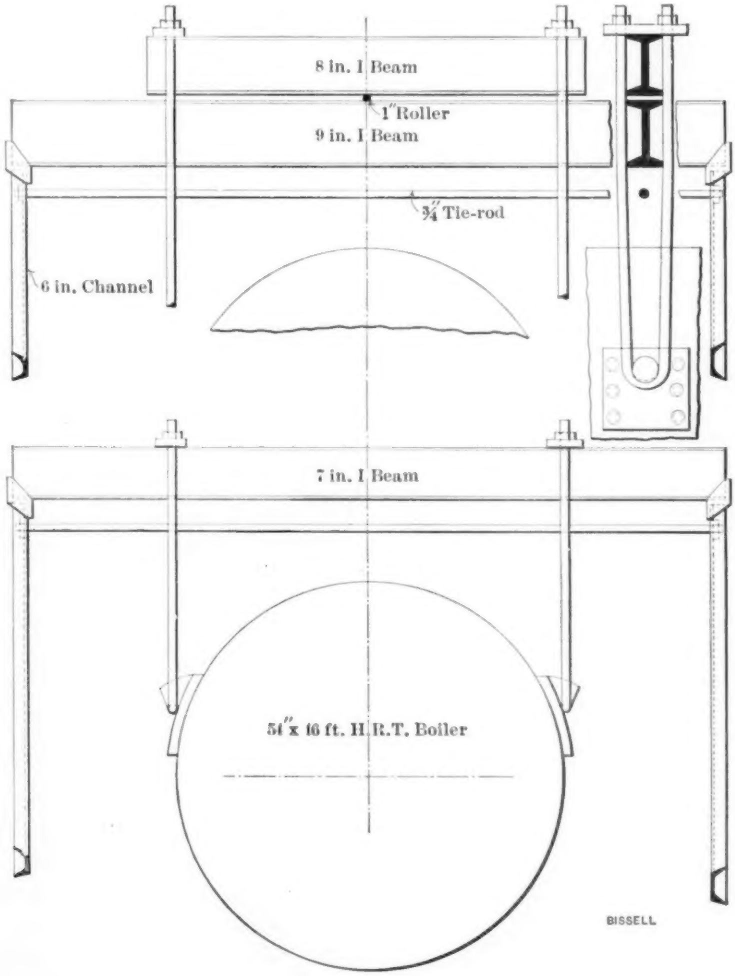


FIG. 18.

Second. Independence of the boiler and the setting, prolonging thereby the life of the setting and making easy the laying up of the new and the repairing of the old brick-work.

DISCUSSION.

Mr. Orosco C. Woolson.—The paper read by Mr. Bissell has interested me in several particulars, for he strikes at points which I have regarded for many years as essential in the proper setting of horizontal tubular boilers. I cannot agree with him, however, in his method of construction, and will take occasion at an early day to present my views in a brief paper to be read before the Society—if possible, at its next meeting.

DCCLIII.*

A SCREW DIE FOR THE TURRET LATHE.

BY JAMES HARTNESS, SPRINGFIELD, VT.
(Member of the Society.)

THE object of this paper is to submit for the consideration of the Society a description of a screw-cutting die, possessing certain novel features, and to mention briefly for comparison some of the other means now employed for the same purpose.

Since design and dimension seem inseparable in machine construction, only the means employed for cutting screw threads within the capacity of the die will be considered, namely, from one-half inch to one and one-quarter inch diameter, and pitches not coarser than seven per inch, and any form of thread excepting that one of the so-called square thread.

This die is intended for turret-lathe and screw-machine use, but may be used on any machine in which the work is rotated. The general features will be seen by reference to the drawings.

The die head proper has a slight lateral and angular freedom of movement relative to its holder, the object being to compensate for a slight change in alignment in the lathe or machine on which the die is used, that takes place when the torsional strain of working takes up the slack of the sliding parts.

The die head is held against the face of its holder by a spring pressure in order to present it to the work in a nominally correct position. The springs allow a slight forward movement of the head, permitting the angular or tipping movement of the die relative to the holder, and also providing a means for opening the die automatically when the travel of the holder is retarded.

The chasers are held in working position by an encircling cam which takes bearing directly over and very close to the front or working teeth, preventing canting of the chaser under working strains. The shape and dimensions of this cam make it unyielding in its control of the diametrical position of the chaser. At-

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

tention is called to the absence of the usual intermediate mechanism between the chaser and its prime controller; also to the general compactness, which is an essential feature in a turret-lathe die.

The form of the chaser teeth plays an important part in the free cutting and accurate leading of the die. Figs. 24 and 25 show the difference in position of the cutting and leading teeth. This difference has been exaggerated in the drawing for clearness of illustration. The exact difference is very slight, but may be made any desirable degree by changing the proportion of the diameter of the milling cutter to the diameter and lead of the work. A milling cutter of two and one-half inches diameter has been used for all chasers from three-eighths to one and one-quarter with satisfactory results.

As shown by the drawing, the teeth at the front of the chaser have a cutting clearance, while the teeth at the back of the chaser have no clearance, but, instead, ride on the thread and control the lead. This gives the cutting teeth an ideal cutting clearance on each side of each tooth and relieves these teeth of the labor of feeding to the die forward.

So accurate is the lead-controlling feature that regular dies for market seldom have an error in lead greater than one sixty-fourth in eighteen inches, which is less than one quarter the average error in standard taps, and less than one-half the error in ninety per cent. of the engine lathes. Thus it is more accurate than the average lead screw and always practically sure, being made by methods insuring invariable accuracy of product and most perfect interchangeability.

The chasers are milled separately in special milling machines using milling cutters of large diameter, having teeth arranged around in circles instead of in the path of a screw-thread. These milling cutters are given an ideal cutting clearance in backing-off lathes, and after hardening are ground to a cutting edge suitable for taking a clean chip, so that the teeth of the chaser can be formed without that rubbing or burnishing which always accompanies the hobbing or tapping of the other dies or chaser, for it is practically impossible to maintain a free cutting edge on either hob or tap of small diameter. The importance of this fact is that the hardening process does not distort the surface of this die, while it greatly changes the lead of tapped chasers or dies, because a compressed or burnished sur-

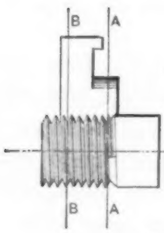


FIG. 23.

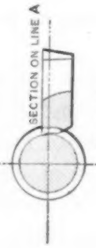


FIG. 24.

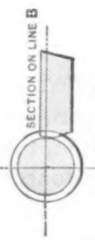


FIG. 25.

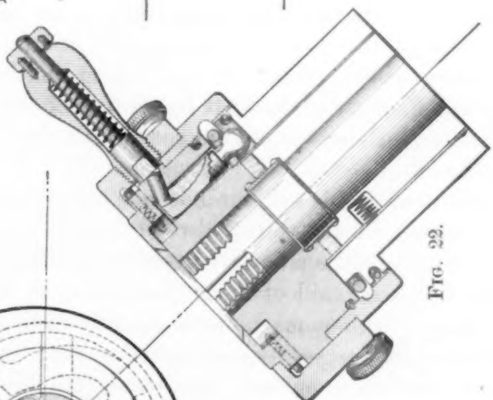


FIG. 22.

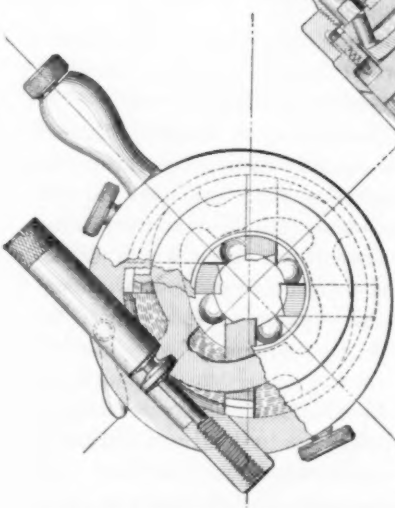


FIG. 19.

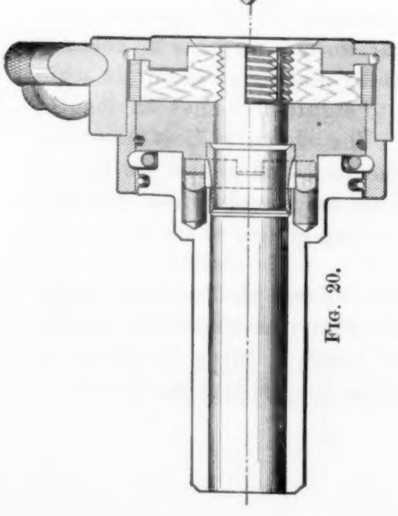


FIG. 20.

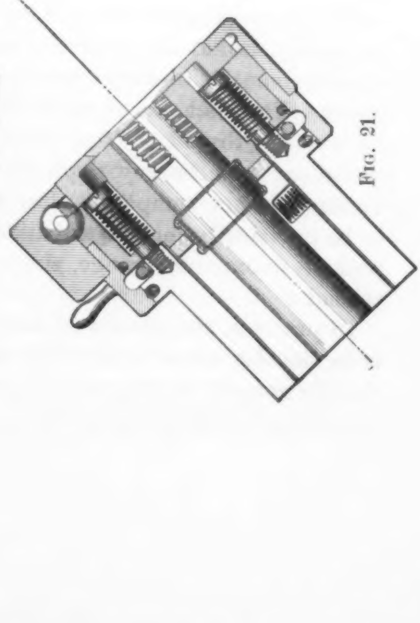


FIG. 21.

face is quick to assume a more natural position as soon as it is heated.

All tapped or hobbed dies have practically four errors. First, the lead screw error of the engine lathe in which the tap or hob is made. Second, the error of hardening the tap or hob. Third and fourth, the double error of changing form of the die in hardening it, due to releasing the compressed metal, and the usual hardening change that takes place at the same time.

By the use of the present method, all errors existing in the milling cutter are corrected in the milling machine, hence the lead is only affected by the final hardening of the chaser, which takes place under such favorable conditions that it produces no appreciable effect.

The outcome of this scheme has not only been a more accurate production of the screw-thread but it has also made it practicable to measure a screw-thread by a reliable means.

All that has been said of the impossibility of making correct leading dies by other methods is equally true of making the so-called thread gauges, consisting of a piece of steel tapped and hardened, but sometimes furnished with a means intended for adjustment for wear but in reality of no value, for it is impossible to adjust such gauges in the direction of their wearing. A more deceptive and unsatisfactory gauge could hardly be devised. Every workman knows that one piece of work may fit a gauge of this kind loosely and yet not enter the tapped hole, and another piece of work may fit it closely and yet rattle in the same tapped holes owing to difference in lead and shape.

The three dimensions of a screw-thread, its shape, lead, and diameter, should be measured separately, if the object of such measurement is to detect the error for the purpose of correcting it. The lead can be measured by placing an accurate scale on a screw-thread of from three to eighteen inches in length, according to accuracy required. The shape is best measured by an ordinary template; after the lead and shape are known to be practically correct, the diameter may be obtained by a flat-pointed micrometer gauge, ring or snap gauge, at the top of the thread.

In practice, the place and time to correct the lead and shape is in the die when it is made, and then the diameter may be readily gauged as the screws are made, it being necessary to occasionally take a test of the lead as the die becomes worn.

DCCLIV.*

A STAY BOLT THREADING DEVICE.

BY JAMES HARTNESS, SPRINGFIELD, VT.
(Member of the Society.)

THIS paper describes a means for threading stay bolts that was mentioned by the writer in the discussion of a paper entitled "Experiments in Boiler Bracing," presented by Mr. Francis J. Cole at the last meeting.

The scheme may be briefly and perhaps completely described as tandem dies for simultaneously threading both ends of a stay bolt to insure an accurate correspondence in lead; the details of which may be mentioned as a means for accurately adjusting the relative longitudinal position of the dies, and employment, at least for the forward die, of some type of opening die not too great in length and not too inaccurate in lead, and possessing good diameter controlling features.

The drawing (Fig. 26) shows the use of the automatic die described in a paper by the writer, entitled "A Screw Die for the Turret Lathe."

Both dies employed should be of the opening type, but the scheme would be equally as accurate if a solid or non-opening die were to be used in the place of the rear die. In fact, if the time consumed in operation were not to be taken into consideration, the front die could be non-opening and used to cut both ends, and in the place of the rear die a nut suitably mounted could be used.

The plate to which the dies are affixed is not necessary when the scheme is used in the flat turret lathe, for in that machine the dies may be attached directly to the turret without the use of the plate.

A brief consideration of the other methods and their results may assist in setting forth the value of this tandem die.

Stay bolts are mostly cut by dies permitted to control their own

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

lead. Occasionally, however, a lead screw is used to govern the pitch of the die. The process of making the dies that have been used for stay bolt threading is unreliable, as shown in the paper entitled, " A Screw Die for the Turret Lathe," and the lead screw scheme seldom controls the lead of the die at the beginning of its cut on account of the slackness of the slides and intermediate connections, hence the die usually has a chance to cut a very

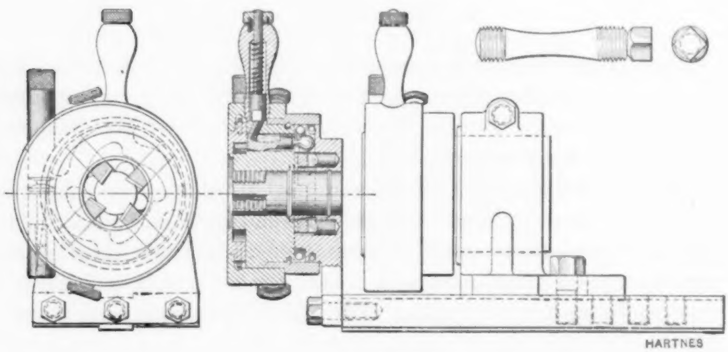


FIG. 26.

incorrect lead before the lead screw has taken up all the " slack " and " spring " of intermediate points.

The springing of the intermediate parts is mentioned because a die that has become a trifle dull will offer great resistance to any means employed to vary its lead.

The excessive clearance of a cutting die as led by lead screws makes the accurate maintenance of size difficult, and also gives a die the tendency to cut " out of round."

DCCLV.*

MACHINE MOULDING WITHOUT STRIPPING PLATES.

BY E. H. MUMFORD, PLAINFIELD, N. J.

(Member of the Society.)

MOULDING machines may be classed under three heads. First, machines which only ram the moulds, and, when the ramming is done by means of a side lever, by hand, are generally called "squeezers." Second, machines which only draw the patterns, the ramming being accomplished by the usual hand methods. Third, machines which both ram the moulds and draw the patterns, ramming either by a hand-pulled lever or by fluid pressure on piston or plunger, and drawing the patterns through a plate called a "stripping plate" or "drop plate"—till recently the usual method—or without the use of this plate fitting everywhere to pattern outline at the parting surface, the patterns being effectively machine guided in either case.

It is to the third class that the machine which is used to illustrate the subject of this paper belongs, and which would seem to have enough which is novel in the application of machinery to the foundry to merit the attention of the Society.

At the risk of appearing pedantic, but with a view to developing an appreciation of the true function of the method of pattern-drawing used in this machine, attention is called to the following sectional views of moulds and ways of drawing patterns occurring in machine moulding. Fig. 27 shows an ordinary "gate" of fitting patterns being drawn from the drag or nowel part of the mould by means of a spike and rapper wielded by the moulder's hand after cope and drag have been rammed together on a "squeezer" and the cope has been removed. Frequently the pernicious "swab" is used to soak and so strengthen joint outlines of the sand before drawing patterns, in such cases as this. In this case, before the cope is lifted, these patterns must be vigorously rapped through the cope; an amount depending

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

(and so does the size of the casting) upon the mood and strength of the moulder.

Fig. 28 shows the stripping or drop plate method of drawing patterns.

In this method, the patterns are not rapped at all and are drawn in a practically straight line so that the mould is absolutely pattern size.

The stripping plate is fitted accurately to every outline at the joint surface of the patterns, obviously at considerable expense, and, of course, at the instant of drawing the patterns, supports the joint surface of the mould entirely. This is, at first sight, an ideal method of drawing patterns, and it has for years

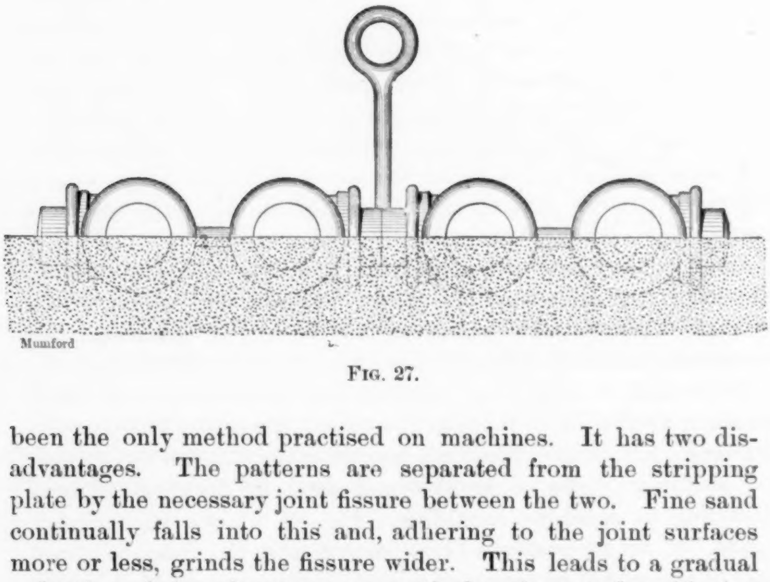


FIG. 27.

been the only method practised on machines. It has two disadvantages. The patterns are separated from the stripping plate by the necessary joint fissure between the two. Fine sand continually falls into this and, adhering to the joint surfaces more or less, grinds the fissure wider. This leads to a gradual reduction of size of patterns on vertical surfaces and a widening of the joint fissure often to such an extent that wire edges are formed on the mould, causing, on fine work, "crushing" and consequently dirty joints. A nicely fitted but worn plate of twenty-four pieces, which had cost, at shop expense only, $250, was recently replaced by a plate of twenty-eight pieces, fitted ready for the machine under the new system about to be described, for not more than $25.

The stripping-plate method has another drawback, not always

appreciated, probably because accepted as inevitable. Stripping-plate patterns are not rapped, and there frequently occur on surface of patterns, remote from the action of the stripping plate, rectangular corners just as important to mould sharply as those at the parting line. Such corners have either to be filleted or "stooled" in stripping-plate work, and neither method often is practicable. When the entire pattern and plate are vibrated so that the corners where the pattern joins the plate draw per-

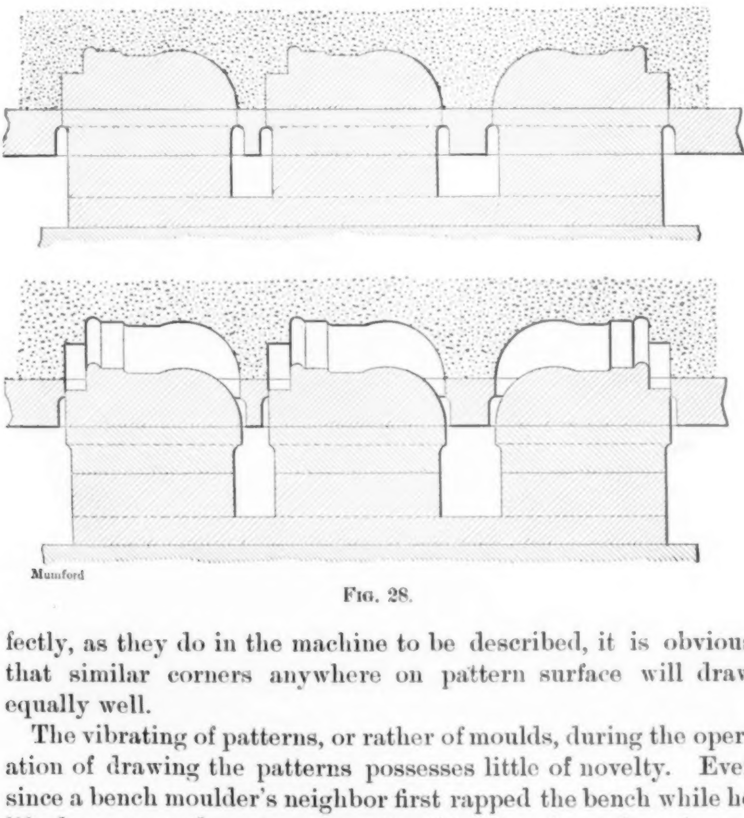


FIG. 28.

fectly, as they do in the machine to be described, it is obvious that similar corners anywhere on pattern surface will draw equally well.

The vibrating of patterns, or rather of moulds, during the operation of drawing the patterns possesses little of novelty. Ever since a bench moulder's neighbor first rapped the bench while he lifted a cope or drew a pattern, the thing has been done in one way or another. In fact, machines are now and then found on the market in which a device like a ratchet or other mechanical means for jarring the machine structure during pattern-drawing renders the working of easy patterns without stripping plates possible.

The idea of applying a power-driven vibrator directly to the plate carrying the patterns, to thus vibrate them independently of other parts of the machine and the flask and sand, has been the subject of the issue of patents to Mr. Harris Tabor, and the following figures will serve to illustrate the mechanism. Figs. 29 and 30 show the general appearance of the machine from the

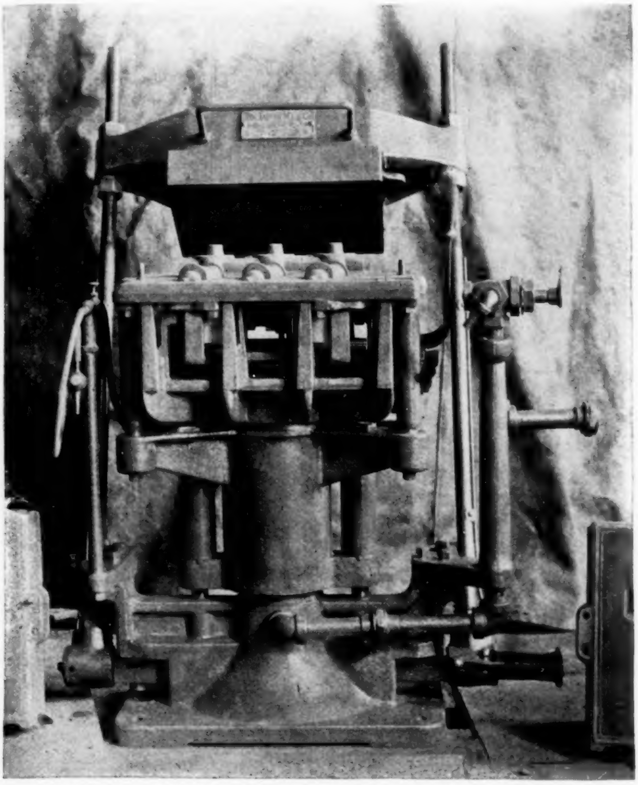


FIG. 29.

side on which the operator stands. Fig. 29 shows the machine ready to receive the flask, the patterns being up ready for moulding. Fig. 30 shows the machine after patterns have been drawn and the flask lifted off.

Briefly, the operation of the machine is as follows: The ramming head shown thrown back at the top of the machine is drawn into a vertical position, after the flask has been placed and filled

with sand. The 3-way cock shown at the extreme right is then quickly opened, admitting compressed air of 70 to 80 pounds pressure to the inverted cylinder shown at the centre of the cut. The cylinder with the entire upper portion of the machine is thus driven forcibly up against the ramming head, flask, sand, and all. Often a single blow suffices to ram the

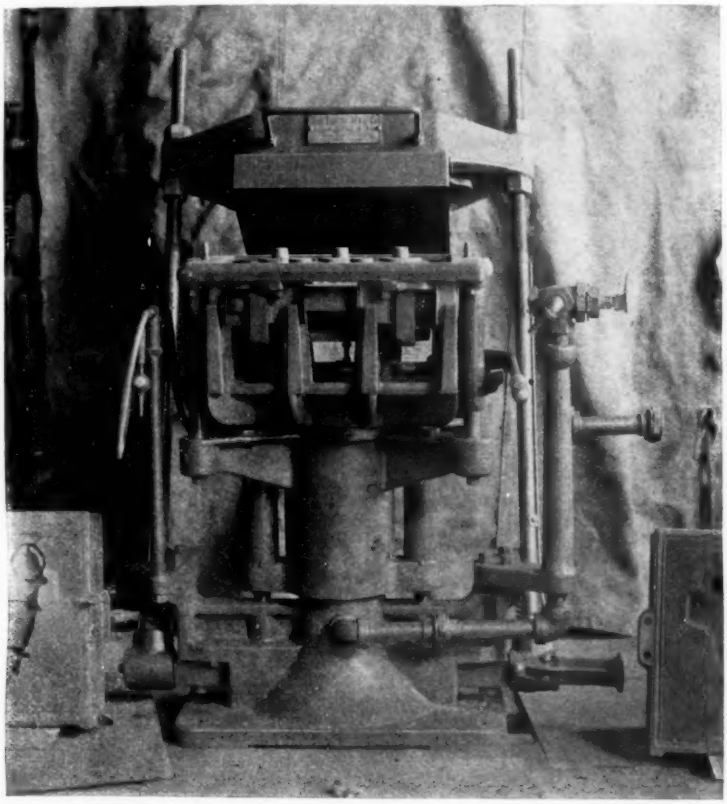


FIG. 30.

mould—often the blow is quickly repeated, according to the demands of the particular mould in hand. Gravity returns the machine to its original position, as the 3-way cock opens to exhaust. After pushing the ramming head back and cutting the sprue, if the half mould is a cope, the operator seizes the lever shown just inside the 3-way cock at the right, and, drawing it for-

ward and down, raises the outer frame of the top of the machine, containing the flask pins, with flask and sand thereon, away from the patterns—thus drawing them from the sand. Just as he seizes the pattern-drawing lever with his right hand, he presses with his left on the head of a compression valve shown

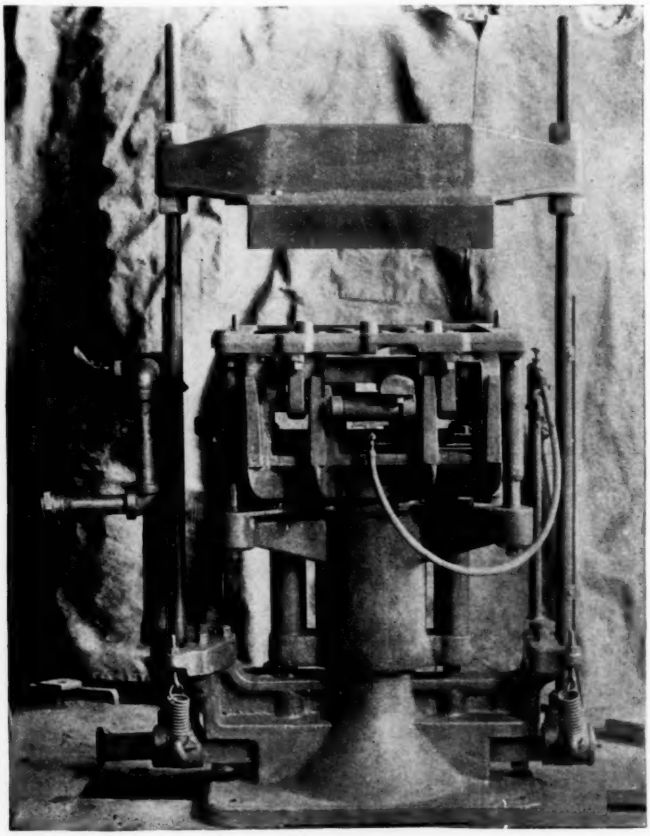


Fig. 31.

at the left side of the top of the machine, thus admitting air to the pneumatic vibrator already referred to.

Fig. 31, a rear view of the machine, shows, at the top centre, with its inlet hose hanging to it, this vibrator, which is shown in section in Fig. 32. It consists simply of a double acting elongated piston having a stroke of about $\frac{5}{16}$ inch in a valveless

cylinder, and impacting upon hardened anvils at either end at the estimated rate of 5,000 blows per minute.

The method of communicating the rapid yet small oscillations of the vibrator to the patterns and yet keeping them from being transmitted to the rest of the mechanism is this:

A frame, called a vibrator frame, to which the pneumatic vibrator is bolted and keyed, is shown in Fig. 33. To this frame the plate carrying the patterns, often, in cases of patterns having irregular parting lines, forming one and the same casting with the patterns, is fastened by the four machine screws, the small tapped holes for which are shown in the four corners. In fact, in changing patterns, the process consists of simply remov-

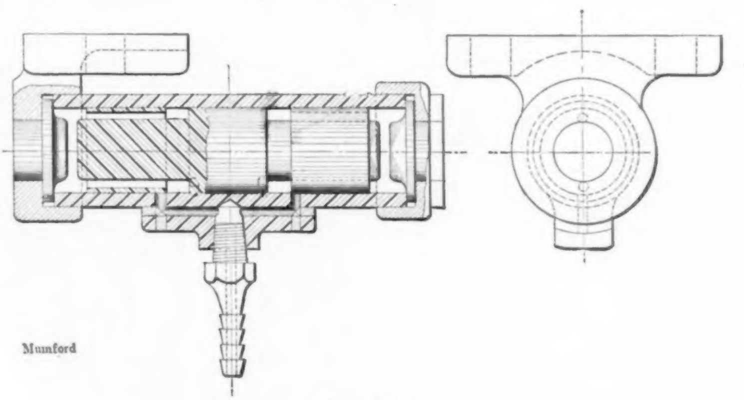


Fig. 32.

ing these four machine screws, taking up the pattern plate and screwing to the vibrator frame the new pattern plate. The vibrator frame itself is secured to the machine structure by the four bolts, the larger holes for which are shown in the inner corners. These bolts are, as shown in Fig. 35, surrounded by thick bushings. These bushings are elastic to such a degree as to absorb the sharp vibrations of vibrator frame and patterns, while so firm and well-fitted as to hold patterns accurately to their position.

The action of the vibrator is such as to give to the entire pattern surface an exceedingly violent shiver, making it impossible that any sand should adhere to this surface, while the magnitude of the actual movement of the pattern is so slight that it is found to fill the mould so completely that it is impracticable to draw it a second time without rapping. Yet, so truly are the patterns

held, and so little disturbed from their original position, that it is perfectly practicable to return patterns to a mould having the finest ornamental surface in the ordinary practice of "printing back."

In cases where deep pockets of hanging sand occur, which cannot be held during lifting off and rolling over, machines are arranged to roll the flask over in their operation and draw the patterns *up* under the influence of the pneumatic vibrator, though, owing to the time consumed in the rolling-over process

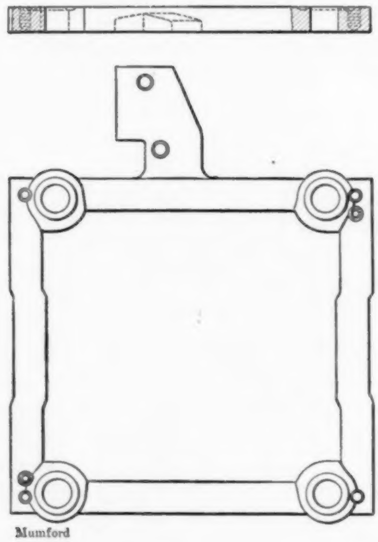


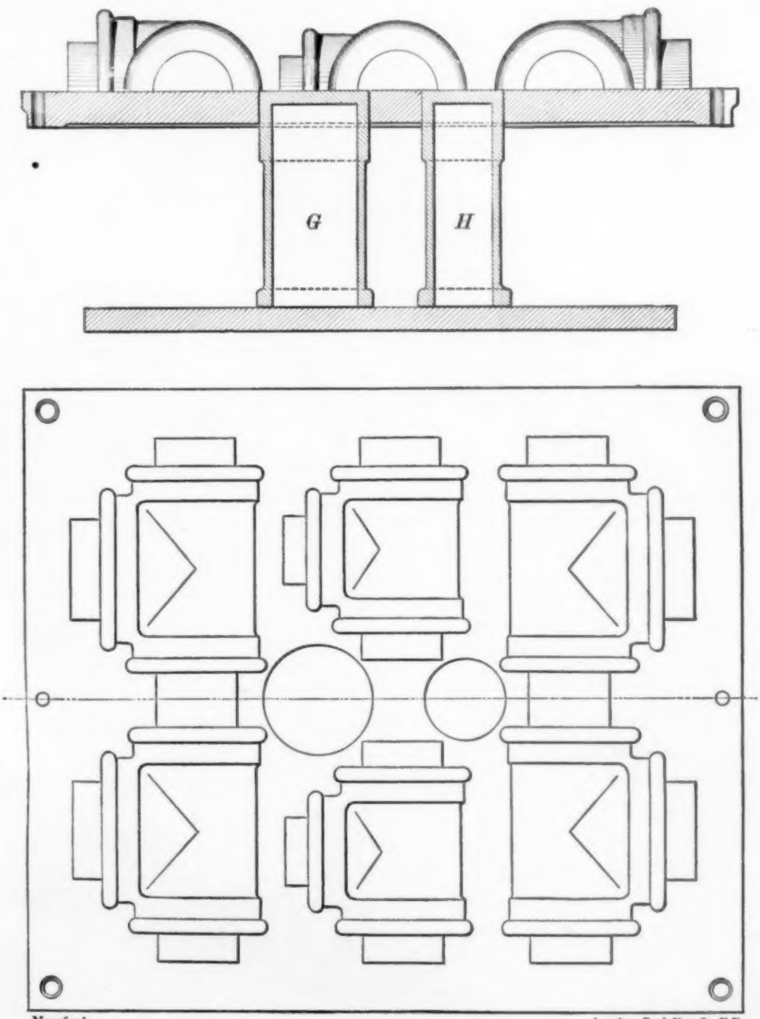
Fig. 33.

(and each operation counts in seconds on a moulding machine), this style of machine is not usually as rapid in its working as the simpler type, in which the flasks come off in the same way they go on.

Fig. 34 shows a set of patterns as they are ordinarily fitted to plates for this machine. Round holes will be noticed at places in the plate surface. These are openings for the insertion of what are called "stools," which are shown at *G* and *H* in sectional elevation.

When it is found necessary to support the sand surface at any point, or generally, round holes are drilled through either

plate or pattern surface and loose cylindrical pieces are dropped into these holes, their upper end surfaces being flush with the plate or pattern surface and their lower ends resting on the



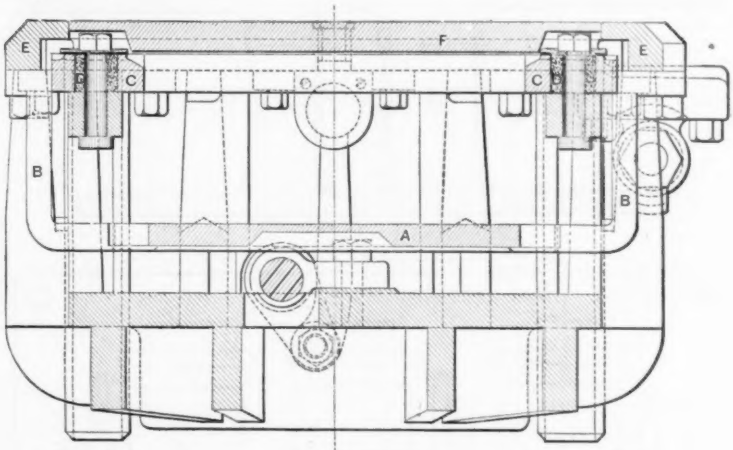
Mumford American Bank Note Co.,N.Y.

Fig. 34.

plate called, from this use, a stool plate. This plate appears in Fig. 35 at *A* and is hung solidly by the brackets shown at *B* from the frame which carries the flasks, so that it has the same

upward motion as the flasks, and the upper ends of the stools remain in contact with the sand of the mould until same is lifted from machine. Fig. 35, showing a vertical section through a machine, will make perfectly clear the position and action of these stools.

As illustrating the importance of being able to work without stripping plates on a line of work which is much more extended



A Stool Plate C Vibrator Frame E Flask Frame
B Stool Plate Brackets D Elastic Bushings F Pattern Plate
Mumford

FIG. 35.

than that possible with them, we may say that a machinist with a drill press, supplied with split patterns and planed pattern plates, has matched and fixed five sets of from four to eight pieces in a day; and wooden patterns fitted for temporary use in the same way, are of frequent occurrence when it is not thought wise to go to the expense of metal patterns on account of the relatively small number of castings to be made from them.

It is not, perhaps, too much to say that pattern expense is not the final evil of the costly and not durable stripping-plate patterns.

DCCLVI.*

NOTES ON RATING ELECTRIC POWER PLANTS UPON THE HEAT-UNIT STANDARD.

(SECOND PAPER.)

BY WM. S. ALDRICH, MORGANTOWN, W. VA.
(Member of the Society.)

THESE notes refer to a paper † on this subject read by the author before the Hartford meeting (May, 1897) of this Society. No comparative data were given in the original paper. It was known that the Committee on Data of the National Electric Light Association had a report in preparation for the Niagara Falls convention, June 8, 1897. This was the fourth and probably the last of such valuable reports. It was deemed expedient, rather than refer to the previous reports, to await the publication of the 1897 report for the data needed in discussion of the author's paper.

The earlier reports of the above Committee on Data have been full of instructive information relating to many types of steam-power electric plants. In all of the cases finally reported, their rating has been based on watt-hours per pound of coal. Over three years ago Mr. F. M. Rites, at the Montreal meeting of our Society, discussed the data of the Washington Convention of the Association (1894). His remarks ‡ at that time were so pertinent to the whole question of the economy of electric power plants that it will not be amiss to quote them here.

"It is impossible that competent engineering ability should be confined exclusively to the manufacturing industries.

"It cannot be assumed that the average intelligence of the

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* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

† *Transactions* of the American Society of Mechanical Engineers, vol. xviii., No. 733, "On Rating Electric Power Plants upon the Heat-Unit Standard," by William S. Aldrich.

‡ *Transactions* of the American Sceiety of Mechanical Engineers, vol. xv., No. 599, "A New Method of Compound Steam Distribution," by F. M. Rites.

designers and operators of electric light stations is inferior to that displayed in establishments of different character, and yet the enormous discrepancy between the actual results and those which should be realized surely deserves some attempt at explanation.

"It is but proper to note that the Committee has chosen the record of a very high duty as a basis of comparison, and that the nature of the exacting service of electric light and street railway plants precludes the possibility of a close approximation to the highest economy under more favorable conditions; but these figures are entirely unexpected and incidentally somewhat ridiculous, considering the energy with which the last per cent. of efficiency of the electric apparatus is insisted on by its users.

"Possibly some reason for such a remarkable state of things may be found in the miscellaneous engineering errors which usually follow an ignorantly wasteful policy, but these are as frequently met in other power plants. Perhaps, also, stations improperly proportioned and generally unfitted for economic competition may be found in the list, but these are far from sufficient to account for such universal failure to realize even a moderate degree of efficiency.

"There seems to be but one general explanation applicable to electric light or railway stations which can account with any degree of probability for such extravagant fuel consumption, and that is the excessive wastefulness of the steam-engine under varying conditions of load."

It is proposed in the present paper (I.) to discuss briefly the progress shown during the past four years in the economic performance of steam-power electric plants as summarized by the Committee on Data of the National Electric Light Association; (II.) to show that the very low economy of such electric-light and railway stations is not entirely due to uneconomical engines and variable loads; (III.) to present a few notes upon a further consideration of the heat-unit rating for such plants. This treatment will have specially in view the necessity for some standard rating by means of which the design, installation, testing, and management, as well as specifications and contracts for these plants, may be reduced to a satisfactory basis for advancing this industry along engineering lines.

I.—PERFORMANCE OF ELECTRIC POWER PLANTS ON A COAL BASIS.

From the several reports of the Committee on Data of the National Electric Light Association, Tables I. and II. have been compiled. An inspection of these will show what little progress has been made during the last four years in such installations. In fact, the expectations of the (1894) committee seem not to have been realized in that they looked for much better values in the reports of subsequent years. It is a matter with which the mechanical engineer is most directly concerned. His work in the design and installation of even the most recent central station is open to criticism that cannot be applied to the electrical features of the same. Electrical engineers themselves acknowledge that the efficiency of the modern dynamo has practically reached the limit set by structural and economic considerations. Mr. Rites' remarks, quoted above, are singularly applicable to the conditions existing at the present day. In the light of what he has said, the following comparative data should be carefully studied by the mechanical engineer.

TABLE I.

SHOWING RESULTS OF FOUR YEARS' PROGRESS IN THE ECONOMIC PERFORMANCE OF STEAM-POWER ELECTRIC PLANTS.

Year.	Convention of the Nat. Electric Light Assoc., at—	No. of Stations Reported.	Watt-hours per Pound of Coal.		
			Maximum.	Minimum.	Average.
1894..	Washington	65	208	25	91.7
1895..	Cleveland	24	262	36	128
1896..	New York	81	237	33	108
1897..	Buffalo	14	269.5	98.7	156

TABLE II.

EQUIPMENT OF THE STATIONS GIVEN IN TABLE I., SHOWING THE MAXIMUM AND MINIMUM ECONOMY.

Year.	Economy.	Boilers.	Engines.	Dynamos.	Daily Output, Watt-hours.	Fuel.
1894	Maximum (208)	....	....	Arc, Power, and Incandescent.	7,971,600	Coal, Hard Screenings.
	Minimum (25)	....	....	Arc and Incandescent.	80,670	Coal.
1895	Maximum (262)	Horizontal Water Tube.	Trip. Exp. Condensing.	Direct Connected.	22,967,952	¼ Soft Coal, ¾ Hd. Screen'gs.
	Minimum (36)	Horizontal Tubular.	High Speed Non-cond'g.	Belted Direct.	2,790,565	Bitumin. Pea.
1896	Maximum (237)	Horizontal Tubular.	High Speed Comp. Cond'g	Belted Direct.	3,270,392	Bitumin. Lump.
	Minimum (33)	Horizontal Tubular.	High Speed Condensing.	Belted Direct.	203,555	Anthracite Buckwheat.
1897	Maximum (269.5)	Water Tube.	Vertical Comp. Cond'g 4-Valve	Dir. Connected, Incandescent.	....	....
	Minimum (98.7)	Horiz. Tubular... and Water Tube.	Comp. Cond'g. Comp. Cond'g.	Belted to Dyn., Belted to C.-Sh.	....	Screenings.

A comparison of the above with some of the best results obtained in modern mill engines has been noted by the committee, as follows:

In the 1894 report compared to the performance of the engine of the Chelsea Jute Mills, Brooklyn, N. Y., showing a coal consumption of 1.482 pounds per indicated horse-power per hour, with the load *varying* from 495.21 to 764.96 horse-power. If such a performance were possible in the central station, it should result in over 400 watt-hours per pound of coal, on the basis of the committee's assumption of 90 per cent. for the mechanical efficiency of the engine and for the same efficiency in the dynamo.

In the 1896 report the committee called attention to the then world's record for steam economy as shown by the Chestnut Hill pumping station engine at Boston—a steam consumption of 11.22 pounds per horse-power per hour, or an effective pump horse-power per hour on 1.34 pounds of coal. If the efficiency of the direct-connected electric generators should compare favorably with that of the pumps of this engine, with no allowance for variation in load, anthracite coal used in the plant with the same economy of installation should produce 557 watt-hours per pound of coal.

In the 1897 report of the committee, Mr. F. R. Low, member of our Society, very fully discussed the several sources of loss

in the electric power plant, stating the discrepancies would be made up mainly from the following items: (1) Decreased boiler efficiency; (2) lesser normal efficiency of engine; (3) impaired conditions of engines; (4) unfavorable engine load; (5) leakage; (6) condensation; (7) auxiliaries; (8) heating. It is not our purpose to discuss this admirable report; but there is no reason why every feature of installation of an electric power plant should not be as fully considered in design and construction as in the case of the modern high-duty pumping station. In fact, it has been repeatedly pointed out that the chief differences are those due to the running conditions of electric plants, and not entirely due to sudden and wide variations of load. Messrs. A. G. Pierce and R S Hale report * of the performance of the Boston stations of the Edison companies: "In our test we have finally found the variation due to causes which we first thought negligible, to be more than the variation due to the change of load."

In this connection it is important to notice the results of Mr. H. A. Foster's analysis of the tests of twenty-two different power plants.† These included manufacturing establishments, electric-light stations, pumping engines, etc. Plants above 200 horse-power show a remarkable uniformity in fixed charges; namely, interest on first cost, depreciation, taxes, and insurance. The operating expenses gradually decrease in plants from 200 to 1,000 horse-power, above which capacity the operating expenses seem to remain remarkably uniform and quite irrespective of load variations. The large electric stations supplying many smaller industries are scarcely affected by the instantaneous load changes in one or more of these particulars.

The conclusions to be drawn from all of the preceding clearly indicate that the economy of the modern high-duty pumping-engine plant is due to a refinement of design and economic arrangement of the installation that has not yet been reached in the electric power plant. Anything which tends to advance the latter industry along the lines which have been so clearly marked out in the development of the former, merit the

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* Quoted by Mr. F. R. Low, report of Committee on Data, National Electric Light Association, Buffalo meeting, June 8, 1897.

† *Transactions* of the American Institute of Electrical Engineers, vol. xiv., "Variations in the Cost of Steam Power," by Mr. H. A. Foster. Paper presented at the annual convention, July 28, 1897.

attention of those having such work in hand. It is believed that the standard heat-unit specifications and the subsequent contract trials of pumping plants upon this basis have combined to develop this industry to an unprecedented degree.

It is not therefore too much to expect that similar standard heat-unit specifications and contract trials of electric power plants will advance this industry also along the same engineering lines. At least the efficiencies, economies, guarantees, and contracts now being realized in pumping stations should be much more nearly approached by the modern electric power plant.

II.—PLANT ECONOMY AS RELATED TO ENGINE ECONOMY AND VARIABLE LOADS.

This seems to be the chief feature of Mr. Rites' explanation of the very low economy of the electric power plants reported upon up to the time of his paper previously referred to. We certainly do not wish to be misunderstood as taking issue with this explanation; but it is apparent, from a careful study of the last four years' record of the Committee on Data, that some very uneconomical engines have produced remarkable results in point of economy of operation and efficiency of installation. The best of engines may be poorly operated on the one hand, and the whole plant badly arranged on the other hand.

We enter as strong a plea as any one for the most economical engine in electric power plants; but we wish to add a further requirement, that there should be economic installation and efficient operation to produce the best all-round results in the course of a day, a month, or a year. We think these two features may possibly have produced the lowest cost of steam power yet recorded; namely, $11.55 per year of 3,070 working hours, reported by Dr. R. H. Thurston,* member of our Society. The plant is at the Warren Steam Cotton Mill, Providence, R. I. The 1,950 horse-power "Allis" cross-compound condensing engine (cylinders: 32 and 68 inches by 5 feet stroke, 74 revolutions per minute), with Heine water-tube boilers, at 155 pounds steam pressure, show an economic performance of 1.35 pounds coal per horse-power per hour.

The question will continue to be asked: Why are not such

* Reported by Dr. R. H. Thurston, in *Science*, October 1, 1897.

results obtainable in electric power plants with similar units? Low cost of steam power or of electric power is not due entirely to multiple-expansion engines of the greatest individual economy; for in the last noted instance, as reported by Dr. Thurston, the cross-compound condensing engine replaced a quadruple-expansion engine.

Concerning the effect of variation of load upon modern electric power plant engines, it is further interesting to note that Messrs. A. G. Pierce and R. S. Hale state of the Boston Edison stations in the report previously noted: "As a matter of fact, the steam per indicated horse-power in our two 200 units holds within 12 per cent. over a range from $\frac{1}{4}$ up to full out-put."

Along the same line it is to be noted that throughout quite a wide range of load variation the compound engines reported by Mr. A. K. Mansfield,* at the recent Hartford meeting, show a remarkably uniform rate of steam consumption. The question naturally arises whether such uniformity under wide variations of load is not more of a characteristic of compound engines than formerly considered by those who lay all the blame upon the steam engine for the poor showing in the economy of electric power stations.

With dynamos which electrical engineers now design and build, maintaining an efficiency over 93 per cent. from about $\frac{1}{3}$ load to 20 per cent. over load, directly coupled to cross-compound condensing engines (let us say) which mechanical engineers are designing and building, having a characteristic low range of steam consumption between similar limits of light load and over load, the question will naturally arise: Why cannot the two units be more economically put together, installed, and operated?

III.—NOTES ON HEAT-UNIT RATING.

In the discussion which followed the presentation of the author's paper on this subject before the Hartford meeting, as well as in conference with members and other electrical and mechanical engineers since, it will appear that the following points have been brought out:

That the heat-unit, as a basis for such ratings, is both rational

* *Transactions* of the American Society of Mechanical Engineers, vol. xviii., No. 727, "The Best Load for the Compound Steam Engine," by Mr. A. K. Mansfield.

and scientific. It is, however, not in consequence the most satisfactory standard for use by builders, contractors, and practical engineers dealing with this class of motive-power machinery; namely, steam engines and dynamos.

That great differences of opinion exist as to the proper definition of the heat-unit required for such a standard. There are at least four different heat-units commonly employed.

That the present extensive and satisfactory use of the heat-unit for steam-pumping installations is as it should be and is all right in that place; but this is no argument for its introduction and use in a similar manner in the rating of steam electric plants.

That the present way of stating the performance of electric power plants, however unsatisfactory, is easily understood by all parties interested. Chief of these, of course, is the capitalist; he can readily comprehend rating based on the coal bill.

That the load factor, after all, has not so much to do with the fuel economy of the plant, as such, however much the varying loads may individually affect any of the units of the installation, such as the steam-engine. Therefore, in the large city and suburban steam-power and electric plants now being installed, there is not the necessity for such strict adherence to economic load factors as in the case of plants with smaller units.

That the watt expresses the activity or rate of the electrical output, in joules per second. In this respect it is analogous to the horse-power rating of mechanical output. Hence, the standard rating should be in kilowatt-hours per 1,000,000 B.T.U. supplied to the steam used in the whole plant.

That if the heat-unit basis is considered as the proper standard for the steam electric plant, the whole heat supplied to the plant should be as carefully determined, and in the same manner, as now in vogue for similar standard ratings and contract trials for steam pumping plants.

That the boiler should be in evidence in all cases in which plant performance is mentioned. In the electric plant it is economy of installation that is desired quite as much as in the case of pumping plants. Why should the boiler performance be urged into consideration in the former case and not in the latter? If it is a good thing to introduce it in either case it would seem proper to do so in both cases.

That the common rating of performance of pumping plants in

foot-pounds per 1,000 pounds steam would be amply sufficient for all purposes of rating electric plants for which the heat-unit basis is advocated. This seems particularly plausible on account of the small variation in the total heat of one pound of steam for quite a wide range of pressures now used in modern electric plants. Taking the standard temperature of feed water at 212 degrees Fahr., exactly 1,000 B.T.U. are required to raise the temperature and evaporate one pound of feed water into steam at 77.3 pounds per gauge (92 pounds abs.). Taking this as suitable for a simple non-condensing engine, we may compare it with that of 150.3 pounds gauge (165 pounds abs.), in which 1,013.5 B.T.U. are required to raise the temperature from feed water (212 degrees Fahr.) and evaporate it into steam at the given pressure. In this case, therefore, if we adopt 1,000 pounds steam instead of the 1,000,000 B.T.U., we make an error of only 1.35 per cent. It is claimed that this is within the usual allowable errors of observation and measurements in power-plant tests, and that there is not enough difference to warrant the trouble required to obtain the performance reduced to a B.T.U. standard.

In this connection it is interesting to note the progress shown by the committee reports on data made to the National Electric Light Association. In ten out of the fourteen cases noted in the report presented at the Buffalo meeting of that association, the "water per kilowatt-hour at best efficiency" is noted for first time. As the average temperature of the feed water in the best stations reported is from 208 to 212 degrees Fahr., and the best results are shown by the compound condensing engines, we may conclude that the comparative water ratings are within about 1 per cent. of what such comparative ratings would be if based on the B.T.U. standard.

It is a question whether mechanical engineers will remain satisfied with results even within this close degree of approximation. The fact has been repeatedly pointed out by electrical engineers that their system of units is altogether unique, is thoroughly scientific (being based upon the C. G. S. system), and is the only system of engineering units universally adopted. Mistakes are said to be occasionally avoided in the sister profession of mechanical engineering by the insistence on the accurate use of terms and of units in electrical engineering. Dealers in electrical stocks and capitalists exploiting electrical

enterprises generally have an appreciative insight into the meaning of volts, amperes, and kilowatts. Why should the time-honored heat-unit be so difficult of comprehension by the same class of interested citizens?

A quarter of a century ago Maxwell wrote: "The consequences of this demand for electrical knowledge and of these experimental opportunities for acquiring it have been already very great both in stimulating the energies of the advanced electrician and in diffusing among practical men a degree of accurate knowledge which is likely to conduce to the general scientific progress of the whole engineering profession."

APPENDIX.

IV.—PERFORMANCE OF ELECTRIC POWER PLANTS ON THE HEAT-UNIT STANDARD.

Since the advance sheets of this paper were distributed, the author has been requested to present some examples of rating central stations on this standard. Though other data have been collected and reduced, yet on such short notice the writer could but turn to the National Electric Light Association Reports on Data, especially as these have been discussed previously in the body of the paper.

In the 1897 Report, the feed-water consumption per kilowatt hour is given for nine of the stations reporting. In addition, six of these report the temperature of feed water. The two preceding data, with the steam-gauge pressures, furnish the means of determining the total heat in B. T. U. supplied to the system, that which is required to raise all of the feed water from its temperature to that of the steam at the boiler pressure. The results are given in Table III.

TABLE III.

SHOWING EXAMPLES OF RATING ELECTRIC POWER PLANTS ON THE HEAT-UNIT STANDARD. REDUCED FROM 1897 REPORT OF COMMITTEE ON DATA OF NATIONAL ELECTRIC LIGHT ASSOCIATION.

Station No. in 1897 Report N. E. L. A.	Pounds Feed Water Per Kilowatt Hour at Best Efficiency.	Temperature of Feed Water, Fahr.	Steam Pressure (Gauge) Lbs. sq. in.	Total Heat B. T. U. in Feed-Water per Pound.	Plant Ratings. Kw. Hrs. per 1,000 lbs. Water, at Best Effic'y.	Plant Ratings. Kw. hrs. per 1,000,000 B. T. U. at Best Effic'y.	Engines. Type.	Rating, at Best Effic'y. Water per I. H. P. Hour.	Method of Driving Dynamos.	Dynamos. Daily Output. Watt-Hours.	Kind of Service Daily.
(1)	(2)	(3)	(4)	(5)	(6)	(7)					
4	23.50	......	160	....	42.60	......	Vert. trip. expansion, four-valve.	15	Direct-con'ted.	200,000,000	Incandescent, 24 hours.
14	26.65	120	115	1100.0	37.55	34.14	Tandem comp. cond'g; double tandem comp. non-cond'g; cross-compound.	17.5	Belted to jack shaft. To dynamo.	124,000,000	Arc and incand., 24 hours.
1	37.50	212	125	1009.5	26.70	26.45	Vert. comp. non-cond'g four valve.	25.8	Direct-con'ted.	13,600,000	Incandescent, 24 hours.
10	38.10	......	112	....	26.30	......	Comp. condensing. Simple non-condensing.	28.5	Belted to dynamos.	3,400,000	Arc and incand., 24 hours.
2	39.30	212	125	1009.5	25.50	25.26	Horiz. cr.-comp. cond'g, high speed, single-valve, aut.	25.7	Belted to dynamos.	1,400,000	Incandescent, 6 to 12 hours.
7	45.00	180	135	1053.20	22.20	21.08	Simple non-cond'g; comp. non-cond'g.	28.0	Belted to dynamos.	13,000,000	Incandescent, 24 hours.
8	45.00	......	160	....	22.20	.. ..	Cross-comp. condensing; tandem compound.	28.0	Direct-con'ted Belt.-dyn.	12,400,000	Arc and incand., Aver. 17 hours.
5	47.70	208	125	1013.50	21.00	20.72	Simple non-cond'g; compound non-cond'g.	29.1	Belted to dynamos.	15,600,000	Arc and incand., 24 hours.
9	53.27	140	120	1080.70	18.80	17.39	Single acting comp. cond'g; simple aut. non-cond'g.	28.0	Belted to dynamos.	2,700,000	Arc and incand., 24 hours.

DCCLVII.*

DUSTLESS BUILDINGS.

C. J. H. WOODBURY, BOSTON, MASS.
(Member of the Society.)

THE increased height of office buildings, rendered possible by what Otis Tufts patented as the vertical railway, while bringing to their occupants relief from the noise of the streets and affording comfort by extending above the fly belt, which is as well defined as the snow line on a high mountain, also exposes the occupants to the fine dust which pervades the whole structure and which the other salutary conditions of the building renders more prominent.

The modern method of heating and ventilating such a building is by means of a blast of air drawn down a flue, warmed, and forced through the building in such quantities that four times the volume of the building is frequently circulated through the rooms each hour.

This method of heating, although a more efficient application of radiating surface for heating the air than by direct radiation in rooms, and which can be managed with far less expense for attendance, repairs, and fuel, and provides the sanitary requisite of ventilation without cold drafts, yet distributes large amounts of dust through such a building; and in a city using bituminous coal under the average conditions there is a fine carbon dust which is especially obnoxious, impairing drawings, books, delicate mechanism, and whatever may be injured by the shower of fine, impalpable dust, which produces black indelible smooches whenever touched. This carbon dust is always an annoyance and at times a serious matter.

The writer undertook to abate the difficulty of dust in a building of nearly 500,000 cubic feet capacity, through which 26,000 cubic feet per minute was usually blown, for heating and ventilation. The outside air used for this purpose was drawn

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

down a flue 37 square feet in cross section, and reached a velocity of 700 feet per minute.

The means taken to remove the foreign substances from the air was by use of cotton cloth filters so arranged that the air should approach the fabric at an acute angle, by which the momentum would carry these particles beyond a point where the element of air under consideration would pass through the filter, and the particles of dust would be carried by the place, and striking the cloth at a lesser angle, tend to glance off and be carried to the bottom of the filter, rather than to clog the interstices in the fabric. The area of the filters being larger than that of the flue, the rate of filtration was inversely slower than the velocity of the air down the flue.

The means by which this was accomplished were very simple. A timber frame, divided by partitions into five rectangular openings, was placed at the top of the flue, and under each opening was placed a bag whose top was attached to a light wood frame slightly larger than the opening, making a tight fit, so that the air entering the flue must pass downwards into these bags, which were over thirty feet in height. An arrangement of guides, ropes, and pulleys enabled the bags to be raised and lowered by a person at the bottom of the flue. The bottom of each bag was made open, and closed with a drawing string, and a hoop kept the lower portion distended. An arrangement of lines extending along the sides, inside and outside, from end to end facilitated turning inside out and back again when they were being cleaned.

The whole of the mechanical arrangement is fully described in United States patent No. 589,772.

These bags were square at the top, where their combined area equalled that of the flue, but soon diminished to a cylindrical section, occupying about 40 per cent. of the space, thus affording ample clearance for the exit of the air passing through the fabric.

The area of the flue was $3\frac{3}{4}$ per cent. of that of the bags, and while the air passed down the flue at a velocity of 700 feet per minute, it passed through the fabric at 26 feet per minute.

From half a peck to a peck per month of fine dust was gathered from the bags.

The efficiency of the device was tested by placing freshly-painted boards at the bottom of the flue before the installation

of the apparatus, and then giving another coat of paint over half of the surface after the apparatus was in service.

In the first instance the fresh paint collected fine dust until it resembled fine sand-paper, and in the second the paint dried with a smooth surface.

Another means of testing the efficiency of the device was by placing split laps of absorbent cotton in various parts of the building before and after the bags were in service, and one set was covered with fine particles and the other was free. The change was not a notable one at first, owing to the large amount of dust previously deposited in the flues, but much of this was removed by running the blower at a very high rate of speed, and afterwards removing the registers and washing them and the flues as far as could be reached.

The device has been solely under the care and management of the men employed on the engine and boilers, and has served its purpose in rendering a building free from dust caused by the ventilating system.

DISCUSSION.

Mr. Gus. C. Henning.—I would like to ask if moisture in the atmosphere would collect upon those cloths so that they would filter less air than when the atmosphere is dry.

Mr. Woodbury.—There is a cover over the top of the flue and the air enters through blinds at the sides; during a heavy rain storm a certain amount of moisture would be drawn into the bags and collect upon the inside surface; then it would be drawn through the cloth and carry a slight amount of fine dust in suspension, and the outside of the bag would be stained by the water trickling down. Snow scours the inside of the bags and removes much of the fine black dust which adheres to the sides until the fabric more nearly resembles black woollen cloth than cotton. As the lower portion of each bag is distended by a barrel hoop and then closed by a drawing string through brass rings, the snow would be removed in the same manner as the dust. The cleaning of the bags was a problem, as the first attempt to use a steam jet inside of a bag turned wrong side out did not prove successful in a district where soft coal was used, as the large amount of coal tar became softened and adhered to the cloth. Afterwards they were washed with satisfactory results, except when they were kept in a washing

machine so long that the cloth became fulled and the interstices were reduced to an extent which reduced the capacity of the filters at the same air pressure.

At present a beating by a carpet beater about once in two or three months will probably serve every purpose in the business and manufacturing portions of a city using soft coal.

Mr. Horace B. Gale.—I would like to ask Mr. Woodbury what this dust which collects is composed of. It would be interesting to know what we are being saved from.

Mr. Woodbury.—The top of the inlet flue was about forty feet high and situated at the rear of very high buildings, except a low building in one direction, and yet the fine black dust appeared to contain every kind of dirt known to be upon the surface of the streets—paper, insects, hair, cotton, wool, and silk fibre, chips of wood, sawdust, tar, soot, ashes, coal, sand, mortar, and iron, evidently from the abrasion of horseshoes and wagon tires.

The specific gravity of the dust, as gathered in a glass jar, was .38, and a little less than a quarter of the weight was organic material.

The difficult part of the problem is the fine soot from chimneys, and it appears to me that it is a mistake to carry a flue so high that the smoke from high chimneys is drawn into the ventilating system.

If the inlet was taken so near to the ground as merely to avoid any hazard from sewer gases from catch basins or perforated manholes, the smoke would be avoided, and the larger amount of sand and coarse dirt could be easily screened from the air.

The importance of placing an inlet flue or blower room so that a boiler setting does not form any part of its boundary is often disregarded, as under those conditions there is a leakage of the gaseous products of combustion through the brickwork and into the air used for ventilation.

The President.—We have heard of the snow belt on the mountains, and Kipling defines the pie belt of New England, but it has remained for our member to define the fly belt in high buildings.

Mr. Woodbury.—I said that in all seriousness, for I supposed that I was merely referring to a well-known fact. It contributes much to the convenience of high buildings that the flies do not

seem to abound in the upper parts of them. It is a matter of general observation, I think, that they are very rare above the fifth floor of these buildings.

The President.—It is a very important element in commendation of high buildings.

Mr. Henning.—I would say that we have studied that in the St. Paul Building. Flies occasionally come up in the elevator to the nineteenth floor, and when they find an open window they will go down. I think 150 feet is the maximum limit at which you will find flies, unless forced up by the wind.

DCCLVIII.*

A STRENGTH OF GEAR CHART.

BY JOHN B. MAYO, BROOKLYN, N. Y.
(Member of the Society.)

IN offering such a simple subject as a gear chart for discussion by members of the American Society of Mechanical Engineers, the writer feels that it is not of sufficiently high order of engineering to be worthy of their attention; neither does he claim any particular credit for himself. He simply offers it on the ground of its representing labor well spent, and its publication would enable others to use it.

In regard to charts, tables, and formulas in general, the writer is well aware that there are those who disapprove of anything of that nature, claiming that each case needs to be treated independently, and also stating that a man should be always ready for his work, whether he has his standard data with him or not. There are others who, like the writer, cannot carry all their knowledge under their hats, and who find it far better to reduce everything which they can to a system of routine, and then have time to spare for research in a new direction, or for going ahead with other parts of the work. It generally happens that a designer is in too great a hurry in his work to make original calculations if at all complicated, and if he does not have access to ready-made data applicable to his case, he is obliged to make a guess, or adopt that of somebody else. Either way is unsatisfactory, in so far as he thinks he could do better if he only had the time. When he does have time to work a problem up satisfactorily it is well if he can leave it in such shape that he will not have the same work to do over again.

In April, 1893, the writer was working on gear transmission. He needed to get a given transmission into a small space, and it was important that it should be well designed. The problem was somewhat difficult, and had been worked on by others be-

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Vol. XIX. of the *Transactions*.

fore he started on it. He had not the benefit of a college education. What knowledge he had was obtained by hard study and a varied experience. He had found odontics well written up, but what he wanted to know was, How small would it be safe to make those gears for that service? On that line he found but little to guide him. After having determined for that transmission as well as he knew how, he set about making a chart so as to have less difficulty in the future. He knew that the different shapes of teeth really affected the strength. This could be solved, but required much labor. He also knew that it would be better to allow different stresses in different cases. Up to that time he had seen nothing better than such formulas as H.P. $= \frac{pfdr}{850}$, and in applying these formulas one would need to use discretion with a range of about 300 per cent., judging from what he saw of other peoples' work.

On May 4, 1893, an article by Wilfred Lewis appeared in the *American Machinist*. Mr. Lewis not only wrote a very able essay on the subject, but he published factors for the shape of the teeth, thus saving any more work on that line. He also gave stresses to be allowed for different velocities, explaining his reasons therefor. This was quite an important step, for if the designer does not know what stresses to use he is in a worse predicament than when lacking other knowledge. The writer then adopted Mr. Lewis's figures and proceeded to make a chart that should enable him and others to select suitable gear almost by inspection. He first plotted a curve having velocities for abscissa and stresses for ordinates to correspond with Mr. Lewis's figures; then drawing an averaging curve among the points, he was able to eliminate the steps from Mr. Lewis's formula. The chart submitted herewith in Fig. 36 is self-explanatory mostly. It only needs to be said that the diagonal lines marked "velocity, feet per minute," are proportional to product of velocity and corresponding stress. If for any reason one desires to allow a different stress than according to Mr. Lewis's rating, the remedy is to multiply the horse-power by a suitable factor. In regard to factors given for other gear, it needs to be understood that if two factors apply to one gear the two factors should be combined. Example: A shrouded gear is necessarily a rough gear. If the shrouding of a pinion increases its horse-power 1.4 times, and a rough gear is of only 0.5 the

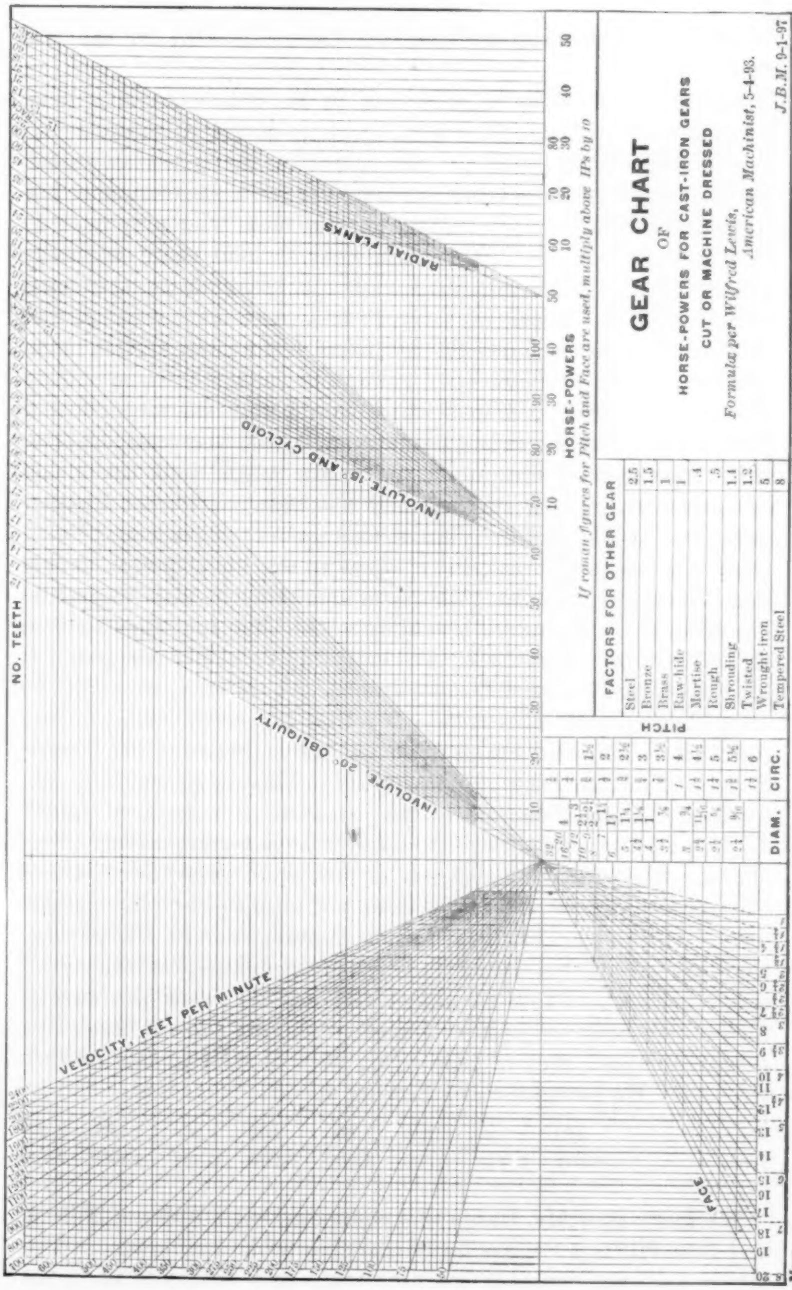

GEAR CHART
OF
HORSE-POWERS FOR CAST-IRON GEARS
CUT OR MACHINE DRESSED
Formulæ per Wilfred Lewis,
American Machinist, 5-4-93.
J.B.M. 9-1-97
American Bank Note Co., N.Y.
HORSE-POWERS
If roman figures for Pitch and Face are used, multiply above HPs by 10
NO. TEETH
VELOCITY, FEET PER MINUTE
RADIAL FLANKS
INVOLUTE 15° AND CYCLOID
INVOLUTE 20° OBLIQUITY
FACE
PITCH
DIAM.
CIRC.
FACTORS FOR OTHER GEAR
Steel 2.5
Bronze 1.5
Brass 1
Raw-hide 1
Mortise .4
Rough .5
Shrouding 1.4
Twisted 1.2
Wrought-iron 5
Tempered Steel 8

FIG. 36.

capacity of a cut gear, we have 0.5 times 1.4 = 0.7 for the real factor.

Example: An electric motor is to be connected to a hoist by gear and pinion. The normal horse-power of motor is 25, and speed 800 revolutions per minute. It is series-wound, and will transmit a greater horse-power for a short time. The hoist is suitable for this motor, but the men who may have to run it may want to lift a much heavier load than originally planned for. This extra load will not break down the hoist because of the factor of safety. It would only wear it out faster. The gears must fill the same conditions. They must not break until they are worn enough to cause their renewal on that account alone. A load which would stall the motor would blow a fuse, and the safety device would hold the load; but five times the normal torque on the motor might pull the speed down one-half, and if the fuse did not blow, or circuit breaker open, the load might be lifted at that speed. This would be $2\frac{1}{2}$ times the normal horse-power, equal to $62\frac{1}{2}$ horse-power at 400 revolutions per minute. The gear ought to be able to handle any load which the motor would up to the time that they become so badly worn as to need renewing. If we select the gear for $62\frac{1}{2}$ horse-power at 400 revolutions per minute, we will be adopting a greater fibre stress for this excessive load than we would if we selected the gear for $62\frac{1}{2}$ horse-power at 800 revolutions per minute, the normal speed. This is proper enough, because the motor cannot do that amount of work as a regular thing, and therefore there would not be a corresponding wear. On the other hand, this stress is just what we would attain if $62\frac{1}{2}$ horse-power at 400 revolutions per minute were the regular duty. If we select the gear for $62\frac{1}{2}$ horse-power at 800 revolutions per minute we would merely be assuming that the speed was constant, and that we sometimes had $2\frac{1}{2}$ times the normal torque, whereas we assumed that we might have 5 times the normal torque. Before proceeding we will refer to Mr. Lewis's stresses. He gave for the following speeds:

Speeds	100	200	300	600	900	1,200	1,800	2,400
Stresses	8,000	6,000	4,800	4,000	3,000	2,400	2,000	1,700

We know that Mr. Lewis was connected with William Sellers, and that William Sellers built machine tools and cranes. The writer does not consider machine tools and cranes to be in the

same class. He thinks those stresses to be about right for machine tools, but rather high for cranes. We will, therefore, select our gear for 62 horse-power at 400 revolutions per minute approximately, and consider them so selected as proper for that 25 horse-power electric hoist. The velocity ratio is to be five, and distance between centres equals 18 inches approximately. We now want two diameters, which shall be to each other as 5 to 1, and whose sum equals $2 \times 18 = 36$, 36 over $(5+1)$ equals 6, $6 \times 1 = 6$, $6 \times 5 = 30$, $30 + 6 = 36$. The pinion will be 6 inches diameter, and the gear 30 inches. Velocity equals $400 \times \frac{6\pi}{12} = 630$.

Inspection of the chart shows that the pinion will have to be of steel. The table, "Factors for other gear," gives for steel 2.5, $\frac{62}{25} = 25$ horse-power to look for in chart. If the pitch equals 3 per inch, we have 18 teeth. The gears are to be involute of 15 degrees obliquity. Referring to the chart, under diagonal marked involute 15 degrees and cycloid, start at vertical line, middle of space, between 20 and 30 horse-power, *fine* figures. Follow up vertically to diagonal for 18 teeth; thence across horizontally to diagonal for 630 feet velocity, an imaginary line, between 600 and 700; thence down vertically to horizontal for 3 pitch, and this intersection is then found on the diagonal for $5\frac{1}{2}$-inch face. If only 15 teeth in the pinion and a less ratio of face to pitch were preferred, we repeat the operation and get $5\frac{1}{4}$-inch face, $2\frac{1}{2}$ pitch. If we had neglected the effect of changing the number of teeth, we would have simply followed on past the 3 per inch to the $2\frac{1}{2}$ per inch and obtained $4\frac{1}{2}$-inch face. But the modulus of the section for same pitch, when there are 15 teeth, is so much less then when there are 18 teeth, that we have to make up for it by not reducing the face so much. We will adopt $5\frac{1}{4}$-inch face for pinion, and 5-inch face for gear. The motor shaft may have $\frac{1}{4}$ inch end play. We will now see if the gear can be of cast iron. Beginning with 5-inch face, we follow on to $2\frac{1}{2}$ per inch, 630 velocity, 75 teeth, and find 40 horse-power. We wanted $62\frac{1}{2}$ horse-power, but right here appears an element which neither Mr. Lewis's formula nor the chart takes cognizance of; that is, although the velocity is the same for both pinion and gear, yet the wear will be about five times as fast on the pinion as on the gear, because the pinion teeth will be in mesh five times as often as the gear teeth. On this account, the writer proposes to adopt cast iron for the gear.

8

By this somewhat lengthy example, the writer hopes to have shown that the chart is not expected to dispense with judgment, but that it is a time saver and that the range of judgment necessary is less than by more common methods.

The writer wishes to acknowledge the assistance he received from Mr. W. S. Dix, and the courtesy of the Crocker-Wheeler Electric Company, who were first to make use of the chart in its original form.

The factors for other gear should not be charged to Mr. Lewis. He only supplied that for steel. (The others were the best the author could obtain.) If discussion should cause other figures to be substituted, one object of this paper would be obtained.

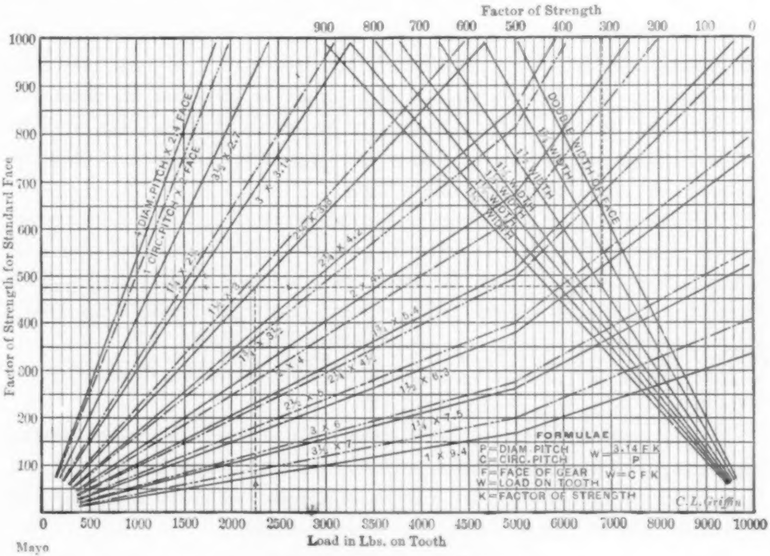
DISCUSSION.

Mr. Chas. L. Griffin.—The paper by Mr. Mayo needs no apology for its presentation. The remarks and chart offered below present no new or startling method of gear design, the chart being less pretentious than Mr. Mayo's, yet I feel that compact arrangement of data is always sufficiently valuable to the mechanical engineer to warrant its being rated in the same class with more original matter.

I have for some years used in designing gears the simple formula $W = KCF$, in which W = load in pounds at pitch line, C = circular pitch in inches, F = face in inches, and K = an empirical factor, ranging from 200 to 400 for cast-iron gears, according to conditions of service. This apparently rough and unscientific rule approaches to correctness when by positive experience the factor K is determined within close limits for any given service, and the value so found used only for gears subjected to that particular service. For example, suppose it is found that the cut gears in the hoisting train of a crane, running with a peripheral velocity of 1,000 feet per minute, give good service under a factor $K = 350$. A very reasonable assumption in future design of such gears would insert this value in the formula. Again, another value might be found suitable for machine tools, another for slow-speed power transmission, and so on.

I realized, however, that the basing of the value of the factor purely on experience was a method which left a gear under new and untried conditions without a definite figure for the factor.

Hence the advent of Mr. Lewis's data, especially in its location in Kent's *Pocket-Book*, was hailed with satisfaction akin to that of Mr. Mayo. The general formula given therein is $W = SCFY$, and on comparison I found that if SY was equated to K, the old familiar formula given above would be realized. As I am partial to charts, I at once set about to make one, which might or might not have taken the form of Mr. Mayo's, had not a careful study induced me to discard the idea of plotting fibre stress, speed, and factor for shape of tooth. The



STRENGTH OF GEAR TEETH.

FIG. 37.

complication seemed to me too great otherwise, and the final diagram showed the relation between four quantities only, viz.: load, pitch, face, and factor of strength. With Mr. Lewis's compact table at hand for values of S and Y, their product, by the exercise of a simple mental process, at once gives K, which is read on the chart.

The chart as herewith (Fig. 37) presented was published under my signature in *Machinery* of September, 1896, with a short description of its use. The face widths assumed as a basis represent good average practice, and the proportional lines for modifying these widths give as great range as is desirable for

any possible case. When these proportional lines are used the factor of strength is read off the top of the chart instead of the side. In this way some reasonable combination of pitch and face for the given load and factor can readily be found. It was considered that the range of pitches given on the chart was as great as required for ordinary power work. The range of load and factors can be extended indefinitely by reading multiples of those given on the chart. For example, a load of 2 × 2,000 on a 2-inch circular-pitch gear would give a factor of strength of 2 × 250.

I think Mr. Mayo's chart tries to do too much. For my own personal use it is too fine-lined. Moreover, it is restricted to the use of the Lewis data. My chart is general, in that the factor can be made up at pleasure from the Lewis data or that of any other authority. It serves as an excellent means of comparing several different authorities.

Mr. Mayo reads his chart in horse-power, and has, I suppose, good reasons for it. I believe, however, the most general and satisfactory way to be to read the actual tooth load. The transformation is simple, either way, but the tooth load reading has some advantage in simplifying the chart.

*Mr. John B. Mayo.**—In view of the possible discussion of the stress allowed, I offer Fig. 38.

The round dots mark the Lewis stresses. The dotted curve is an equilateral hyperbola, and shows by comparison with the round dots how near the Lewis stresses come to making the velocity useless in figuring the horse-power.

That is to say: If the allowable stress were inversely as the velocity, we would find that in a train of gears we would get the high-speed gears as large as the low-speed gears, notwithstanding the lower tooth load. The other extreme would be to select all gears by common formulæ wherein the stress is constant, independent of velocity. Such a condition would be met by a horizontal line.

It has been pointed out to me that if a train of gears consisting of two pairs, each pair being of same diameter and velocity ratio, but the velocity at pitch line being 700 feet per minute for one pair, and 1,500 feet per minute for the other, were selected by the chart without modification, that the pitch and

* Added after adjournment.

face of the high-speed pair were nearly as great as of the low-speed. I argued that, for work subjected to severe shock, as in cranes, if it were not so, the high-speed gears would be the first to break, for they would become worn faster, and having been worn an equal amount, it would be more effective on the originally thinner teeth.

For steady work, as in pumps, I am now inclined to think that a curve like the full line will give better results than the Lewis' stresses, and I hope at some future time to make a new chart for use in power or electric pumps.

I think this an improvement over that at Fig. 37. The diam-

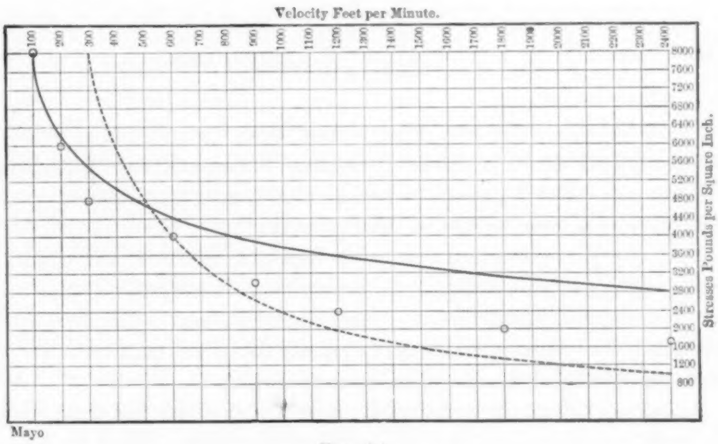


FIG. 38.

eters corresponding are 6 and 30, therefore velocity becomes 630.

I * appreciate Mr. Griffin's discussion, but I am disappointed in that no one attacked what seemed to me to be the weaker points.

The efficiency of any time-saving device depends upon the conditions under which it is handled, and the familiarity with it of the persons who use it.

I endeavored to show that while the chart was not expected to dispense with judgment, it did not preclude it.

Mr. Griffin admits the value of the Lewis data, and refers to

* Author's closure under the rules.

their applicability in Kent's *Pocket-Book*, and their use in determining the factor K in his formula.

For my own individual practice, if I desire to solve a simple formula, such as $WKCF$, I would use a slide-rule only. But see how much this factor K means. It includes the Lewis factor Y, which varies from .154 to .052 in extreme cases, and from .124 to .067 in everyday cases. As this is a positive quantity and the designer cannot change it, I think, if a chart is used, that the factor Y should be included in the chart. If, as I have it, included under "No. Teeth," no one needs to inquire its value. It is enough to know that whatever it may be, it is there, and not to be considered elsewhere.

It seems to me that the factor K must have a greater range than 200 to 400 for $\frac{.067}{.124} = \frac{215}{400}$ approximately, not to mention other variables.

It is because, for anything other than rough guess work, a table of factors or a chart becomes necessary to supplement a slide-rule that I prefer to use a chart, and when looking at a chart, we might as well read off the final result at once if possible.

But complete standard data serve a yet more important purpose. They allow a chief to make use of assistants who may not be as well qualified to use judgment, and even for those who may be better qualified, it is desirable that there should be uniformity in details for similar machines.

An expert draughtsman will often be slow in his work if he is confident that his chief will change his design when he comes around to look at it.

Consistency in a chief's judgment plays an important part in the accomplishment of much useful work, and the giving out of standard data to subordinates is an efficient means to this end.

In regard to the fine scale, I may say that original tracing is 10 inches by 16 inches.

I have never used teeth of 20 degrees obliquity or radial flanks, and, in making another chart, dispensing with these would allow of smaller size and larger scale.

DCCLIX.*

THE VALUATION OF TEXTILE MANUFACTURING PROPERTY.

BY CHARLES T. MAIN, BOSTON, MASS.
(Member of the Society.)

THE engineer is called upon to place valuations upon manufacturing property for various purposes, as buying or selling, raising money upon or bonding a property, rental, taxes, insurance, adjustment of losses by fire or accident, and condemnation where private or corporate property is taken by the State or town for public improvements.

I shall confine my remarks to the valuation of textile manufacturing plants, and property usually connected therewith; but the same principles will hold good in the value of other properties, the application being made to suit the peculiar conditions of the business under consideration.

The court in Massachusetts has established that the true value of a property is its market value, and substantially that the market value is such a sum as one party who has the capital, and who desires to purchase, is willing to pay for a plant, the owner being willing, but not forced, to sell.

It would seem at the first glance that there should be but one value for a plant for any or all purposes, and that value should be its market value. This is the value which is most important of all, and upon which all other values largely depend.

MARKET VALUE.

Let us therefore consider, first, what is the "market value" of a plant, and what elements enter into the determination of such a value.

The Methods of Determining Value.—There are a great many who place more confidence in the off-hand estimate of the practical business man than in a careful estimate of value by an accountant or engineer; but if the latter combines with his careful

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions.*

weighing of each element which enters into the whole plant a general business knowledge and a large quantity of common sense, the result will be nearer the truth than the off-hand value which has considered these elements in a general way only. It is not unlikely that the results might agree very closely, thus confirming the opinions and judgment of both.

By whichever method the value is determined, there must enter into it, either consciously or unconsciously, certain fundamental elements which determine its value.

Comparison with Other Properties.—The prices brought for small pieces of property, as house-lots, houses, and such properties as are being sold frequently, are a measure of value for comparison of adjacent and similar pieces of property; but the sale of a large plant is not an every-day occurrence, in fact it is a very rare occurrence; and the conditions which have made the sale necessary, and which surround the sale, and of the plant itself, are usually such that the prices realized cannot be used as comparative in determining the actual value of another somewhat similar plant surrounded by other conditions.

Elements of Value.—Into the market value of a plant enters the broad element of location, with its varying hours and price of labor; skill and abundance or scarcity of operatives; cost of transportation of raw material, supplies, and finished product; cost of fuel or power; cost of construction and equipment; and rate of taxation. Also the narrower and more restricted element of the physical condition of the plant and its relative value to a new plant constructed upon modern principles, and constructed with all regard to the economical production of a finished product of the best quality of the goods manufactured. The standard of value should be a modern mill constructed as described above, and located so as to avail itself of as many combined advantages as possible.

The ultimate value of a plant is its capability of producing a profit, and into the possibility of producing a profit enter all of the above items and perhaps some not mentioned.

Management.—The question of management is a personal one, and must not enter into the problem, except so far as to make sure that with good management the business would be successful. The business of a large and valuable plant might be conducted in such a manner as not to realize a profit; but it might, nevertheless, have great value, and would bring a large amount

if offered for sale. On the other hand, a plant not nearly so valuable might, with skilful and close management, yield a profit; but if offered for sale would bring very little. Although the past profits of a concern will have some influence in determining its value, they are not a measure of its value; because a purchaser might by different management reverse the profit or loss, or the changes, real or anticipated, in trade might do the same thing. We must therefore eliminate as far as possible all personal equations from the problem.

Choice of Location.—Textile manufacturing requires considerable power; the cost of labor is a large part of the value of the product; the labor must be skilled to produce a satisfactory product; and the cost of transportation of raw materials and finished products is considerable. All of these items require attention in estimating the value of a plant with reference to its location. If a new plant is to be built, all of these can be weighed approximately; but if an existing plant is to be valued, the relative cost and effect of the fixed location with that of the more favored one must be determined as nearly as possible.

It is the balance of the sum of these items in favor of the South which has caused the rapid increase of southern mills in the last two or three years, and which has caused the northern cotton manufacturers of a certain class of goods to locate their new mills there in preference to the North.

There exist there the following advantages: in some locations, less cost for transportation of raw materials and finished products, low-priced fuel, low rates of taxation, longer hours of labor at a less price than in the North. This last item of advantage may in time, if there is a great demand for labor, adjust itself, so that there will be no advantage in this particular over the northern mills.

The most skilful employees in the North are, as a rule, found in the large manufacturing centres, and, of course, are more numerous there, and the concern is not dependent upon a very limited few for its operation. The operatives enjoy living in a live, bustling place, where there is excitement and entertainment, rather than in some quiet country place. Whether it is better for them or not does not enter into the question. On the other hand, the smaller concerns, located in the country or in a small town, can hire their help at a somewhat lower price than at the larger manufacturing centres, and are freer from labor troubles.

On general principles, I should say that the balance would be in favor of the larger districts.

Transportation. — The cost of transportation is more definite and tangible. Although it varies somewhat from time to time, it is not very likely that there will be any radical change unless by the construction of new railroads or canals.

The weight of the raw materials and the finished product in a cotton mill are approximately the same, and in a woollen and worsted mill the weight of the finished product is less than the weight of the raw material, varying with the fineness of the product. It is desirable, then, that the mills be located so that the cost of freight on the raw material shall be as low as possible, other things being equal, and that the distance to the consumer in time and distance shall be small.

The item of carting is in some instances a very considerable expense. Unless the mill is located on a side or spur track, or on navigable water, it may be necessary to do a large amount of carting. This is usually one of the drawbacks connected with the development and use of a water power situated at a distance from the railroad. The difference in cost of teaming between a location on a branch track and a location at considerable distance is a definite amount, which, if known, can be used in the determination of the value of the plant, and the extra cost of transportation can also be treated in the same manner.

The effect upon the values of a property of excessive charges for carting and freight is to reduce its value, and the amount of reduction will vary somewhat, according to the return which a man or corporation is satisfied with. I should say that, taking into consideration the uncertainties of the future, one would be warranted in making an expenditure which promised a return of ten per cent. on his investment. That is, if a person is considering the purchase of a property, and finds that the extra cost of carting and freight would be $1,000 more a year at the fixed location of the mill than at many other locations which might be chosen for a new mill, with all other conditions equally as good, that he would say that he could afford to pay $10,000 more for a mill at the more favored location than for the one under consideration; or if the mill is to be purchased with this incumbrance upon it, that its value would be $10,000 less than if situated at the more favored location.

The situation is equivalent to the mill having a mortgage upon

it which requires the payment of $1,000 a year for all time, and the net value of the property to a purchaser is its full value less the amount equivalent to the $1,000 tax.

Centres of Trades.—There are certain localities which have become centres for certain classes of work, where skilled workmen in their particular trades are in abundance, and which may have other distinct advantages. There may be a choice between several centres devoted to the same class of work, the balance of the sum of all the advantages being in favor of one particular place. Into this sum enter the items explained before, and some other items which can be determined quite closely in money value.

Taxes.—The rate of taxation and the method of valuation for taxes may afford a decided advantage to some particular location. This is a part of the fixed charges of the plant which is always visible, and which goes on whether the business goes on or stops; and the value of a plant to a person free to purchase and locate at the place under consideration, or in any other location, is affected by the amount of taxes levied upon the concern.

In the same way as for greater cost for transportation, the greater cost for taxes would warrant an expenditure of an amount which would return an income of about 10 per cent., and would therefore decrease the value to a prospective purchaser by that amount.

Municipal Government.—A more remote item, and one which cannot be figured in dollars and cents, is the general character of the municipal government and its attitude towards industrial enterprises. In most towns or cities at the present time there is an attempt to attract manufacturers by concessions direct or indirect. There are other places which do not care to have manufacturing establishments within their limits, and others in which there is an undercurrent towards crowding the various industries, and making them pay the largest amount of the taxes which they will stand, for which they, as corporations, receive very little direct benefit.

Cost of Construction.—The cost of construction in one place may be less than in another, and the purchaser having his choice of locations should consider the effect of this item. Clearly, if all other things are equal, one could not afford to pay any extra charge for construction and equipment of the mill more than the cost at the most favored location, and the value of an established plant must be diminished by an amount which represents the dif-

ference. This sum stands for itself, with no capitalization, and is probably as definite as any which goes into the sum total. The difference can be obtained by investigation of the costs of material and labor, and the costs of machinery and supplies, erected and ready to run.

Cost of Power.—The cost of power, which is another one of the fixed and general expenses of a mill, has always been a problem in the determination of a site. Cheap fuel is to be desired, especially where large quantities of steam are required for other purposes than power. The location in which coal can be purchased at a low cost has a distinct and definite advantage in this respect over the location in which the fuel cost is large. Between mills driven by steam power alone this item can be closely estimated and the proper deduction of value made to a purchaser, or the amount estimated which he can afford to expend for the sake of getting the cheaper fuel.

Water Power.—It very often happens that a mill whose value is under consideration is driven partially by water power—very rarely is it driven wholly by water power—and the approximate estimate of the value of the power must be made.

The value of a water power has been fully discussed by the writer in a paper before the American Society of Mechanical Engineers, vol. xiii., cccclxxi., and will not be treated in detail here; but some portions will be repeated, with the conclusions drawn, and some further remarks made.

It is easier to determine the value for a specific business than in a general way.

The essential points which must be considered, as to whether an undeveloped power can be developed and used to a greater profit than any particular business or the general run of business could be conducted elsewhere with a different source of power, are as follows:

Quantity of water, uniformity of flow, head, conditions affecting the cost of construction, freight charges, use of exhaust steam, need of water for other purposes than power, and more uniformity of speed attainable from steam power than from water power.

The determination of the flow is not always easy. The flow can be measured at intervals, but a continuous record is needed to get at the flow with much exactness. In many places no records are kept which are of any value, and the only recourse is

to estimate the flow from the rainfall and character of the watershed, and by comparison with existing records of similar streams.

The power which has the most value is one which has a flow during a dry year which is nearly constant, or which can be made so by storage basins, and which requires no augmentation from other sources. Its value can be determined by comparison with the cost of uniform power produced in a fairly economical manner, at any place or places equally convenient to the place at which the water power is located, for the transaction of the business under consideration.

The value of an undeveloped constant water power is such a sum as when put at a proper rate of interest, say 10 per cent., will pay the difference in cost between steam and water power, all items of cost being considered.

A power which is variable, and which cannot be depended upon throughout the year, has of course less value than one which is constant. In such a case the items for consideration are:

The maximum, minimum, and average quantity of water, and length of time when there is no water; all the other items which enter into the value of a uniform power; necessity in nearly all cases for a supplementary steam plant, with the expense of maintenance and running for a portion or all of the time.

The value of an undeveloped variable power is little or nothing if its variation is great, unless it is to be supplemented by a steam plant. It is of value then only when the cost per horse-power for the double plant is less than the cost of steam power under the same conditions as mentioned for a permanent power, and its value can be represented in the same manner as the value of a permanent power has been represented.

To determine the market value of such a power which has been developed, it will be necessary to consider the power by itself, independent of the plant; that is, to determine first the value of the power as though it were undeveloped, and then to determine the value of the improvements. The sum of both will represent the value of the power as developed.

It might happen in some cases that the value of the privilege would be a minus quantity, but that the value of the improvements more than offset that, thus making it of value in the developed state.

The cost of developing a power originally will not always represent the value of the improvements, except in so far as it relates

to the character of the work done. Considering the work properly and substantially done, the value of that work immediately after completion may not be represented by its cost. A certain power may cost to develop twice as much as another of equal power, the difference in cost being due to difference in head or some other natural cause; but, all other things being equal, the one which cost double has no more value than the other, because it produces no more.

The value would depend largely, however, upon the character of the work done and the condition of the dam, canal, and wheel plant. If any portion required renewing soon, the value would be lessened; and if a general renewal of all the plant were necessary, the value would then be practically the same as though it were undeveloped.

The actual value of a plant would depend upon the amount of depreciation which had taken place; or, better, upon the number of years which it would run without renewing.

The value of the plant will be its cost, less depreciation, up to the point where the cost of water power equals that of steam power; for it would be justifiable to make an expenditure up to an amount which would give as good financial returns as any other source of power. Beyond this point, when water power costs more than steam power, the value of the improvements would not be represented by their cost.

The value of a developed power is as follows: If the power can be run cheaper than steam, the value is that of the power plus the cost of the plant, less depreciation. If it cannot be run as cheaply as steam, considering its cost, etc., the value of the power itself is nothing; but the value of the plant is such a sum as could be paid for it new, which would bring the total cost of running down to the cost of steam power, less depreciation. That is, it is worth just what can be gotten out of the plant, and no more.

Although the water may have no value for power, it may have considerable value for dyeing and washing purposes, and its value for these purposes can be based upon the charges made for such water in manufacturing centres where the water is suitable for such purposes.

If low-pressure steam is required for heating purposes, and exhaust steam can be used, the heat thus saved should be credited to the cost of coal for running the substitute plant, and the

cost of attendance should be proportioned between cost of power and cost of heating.

In order to have a standard of value for comparison of costs, it is necessary to estimate the cost of producing a constant power by water alone, if the water power is constant, such as that at Niagara Falls, on the present development for power, or by water power supplemented by steam power at such times as are necessary to produce a uniform power, and to compare this with the cost of producing a constant and equal amount of power by steam alone. There may be some exceptions to this rule where the power to be used is not required to be absolutely constant, as for a saw mill, grist mill, and certain kind of paper mills, where a large stock of pulp is ground up in the wet season and stored for use in summer.

In nearly all cases to be considered, the power is variable, and no true comparison of its value can be made until it is made constant by some supplementary power, at least for textile manufacturing, which requires a uniform power. It is the result of omitting this important factor in the value of a water power which causes the values given oftentimes to appear beyond reason.

In estimating the damages by reason of diversion of water power, it is customary to capitalize the difference in cost in favor of water or against steam power at about 5 per cent. This damage has been done against the owner's wishes, and he is entitled to a capitalization at a smaller rate than would be done in an investment where the purchaser is of his own free will assuming certain risks, as damages caused by freshets, which he will not assume for nothing. He is also basing his comparisons upon the steam plant with its present efficiency. For these reasons the difference in favor of water power should be capitalized at not less than 10 per cent.

It is not impossible that some cheaper source of power may be discovered, thus destroying our present standard for large powers. For small powers we already have the gas, gasoline, and oil engines, and in some places electric power can be bought. Any of these may be used as a standard of value if adapted to the work and circumstances.

PHYSICAL PROPERTIES AND VALUE OF A PLANT.

The valuation of property as made by different individuals will vary according to their ideas of the proper return to be obtained

from such property, and upon their judgment as to the proper amount of depreciation to be allowed. In determining such a valuation, comparison must be made with the cost of a new and model plant, and between the costs of operating the old and new plants in so far as the organization of the old plant is detrimental to economical running, when such poor organization cannot be rectified. When it can be changed to a proper organization, the cost of making this change must be deducted from its value if such defects did not exist.

The value depends primarily, but not necessarily, on the first cost of the property under consideration, which might have been excessive at the time of its inception; nor necessarily upon the first cost to-day of a plant identical to the one under consideration; for a smaller plant, owing to improvements, might be installed to-day which would produce the same results as the one under consideration. The first cost to be used in comparison, then, is the cost to-day of a plant which will produce equal results in quantity and quality as the one under consideration.

Buildings.—The value should be determined by comparison with the cost to-day of a new structure with all the modern and improved ideas with regard to style of construction, large amount of window area, arrangement and size of rooms and buildings with reference to convenience and cost of operation and space occupied.

A mill or building with the old style of joisted construction, with low stories and small windows, and with a large number of small rooms, even if new, would not have the value of a modern mill building, with higher stories, large percentage of window area, and large, clear floor areas.

To get the selling value of a building, the cost of a new and modern building should be depreciated:

First. For the difference in style of construction.

Second. For lack of light, which makes it necessary to produce more artificial light.

Third. For the amount of floor space which is unavailable, due to the subdivision of the space or to the style of construction.

Fourth. For the increased cost of operation due to inconvenience of arrangement of rooms or buildings.

Fifth. For the increase in cost of insurance over that on a modern mill.

Besides the actual cost of producing artificial light where it is

dark, which can be estimated, there is a loss due to a little less production, also because the production is not fully equal in quality to that made where there is plenty of daylight.

The amount of this depreciation for the difference in style of construction would vary, decreasing as the building approaches in strength, form, and convenience that of a modern structure. The depreciation for lack of light can be determined if it is known how much more artificial light must be burned, and the extra expense of the same, and capitalizing this at the proper rate of interest. The depreciation for inconvenience and extra cost of running could be determined if the extra cost of running is capitalized at the proper rate. The depreciation for unavailable floor space is just the percentage which cannot be used. The depreciation on account of higher insurance rates can be estimated by ascertaining at what rate the factory insurance companies would take the risk with buildings constructed according to their ideas, and to find the difference between the cost of insurance on the old plant and the new one. This difference would represent interest on a sum which one could afford to lay out on new buildings, or the sum which the old buildings should be depreciated on this account.

The proper rates at which to capitalize these amounts would vary according to the idea which a person might have as to a satisfactory return for money expended. It is safe to say that any one would be willing to make an expenditure towards a new building which would return 10 per cent. gross on the investment. If an old building is replaced by a new one, the charges for taxes, insurance, and depreciation will be no more, and probably less, than for the old building.

From the above it appears that, if the extra expense in total cost of running due to the inconvenience of the building is 10 per cent. of the cost of new buildings, the buildings are valueless for the purpose to which they are put, because an expenditure for new buildings would return 10 per cent. on the investment.

It might be possible by certain changes to make the buildings as light and convenient as modern buildings, and if new, they would be equal to the cost of such modern buildings minus the cost of making the changes.

After determining the value of the buildings, if they were new, according to the above method, there remains to be applied the depreciation from age. This to a certain extent must be an arbitrary

quantity, but based upon the average life of buildings of the character of those under consideration. It would seem that one per cent. a year is little enough for brick buildings substantially built, credit being given for any extraordinary repairs, renewals, or additions.

We must not lose sight of the fact that, although a building may not at the end of 100 years be completely worn out, the character of the business may so change that the buildings are not adapted to it, and that they will be rebuilt, as we have seen the older buildings replaced with new ones of different style.

The depreciation of wooden buildings is greater than brick, depending upon the purpose for which they are used. Buildings which are kept dry, and not subjected to much wear and tear, would, if well built, last a hundred years; while wooden dyehouses, subjected to steam and wet, will not last over, say, twenty-five years.

The length of life depends largely upon the care which has been given to repairs. If the roof is kept in good condition and woodwork well painted, the depreciation is less than if no care is taken.

If any marked renewals have been made, credit should be given for them. A whole new floor or roof may have replaced an old one, thus making that portion practically as good as new.

The first cost of a modern mill is the measure of value for the building under consideration, and not the first cost of this particular building; for the building may have been built in a very expensive way, highly ornamental, or in a location which caused very expensive foundations. None of these extra costs add anything to the productive value of the plant, and therefore must be sunk out of sight.

The large first cost of a concern may be a heavy burden for it, as the fixed charges must go on in larger amounts than they should, and it may be that not until this extra cost is charged off the books, or the capital shrunk enough to bring the charge against the plant on an equality with other mills, that a profitable business can be done.

Land.—The value of the site will vary in different places, and under different circumstances. In some cases certain restrictions are placed upon the land in connection with the water rights, and the value of the land itself cannot be separated from that of the water rights. The value of adjacent and unrestricted land is no

guide to the value of the site. Its market value by itself might not be a very large amount per square foot.

In some cases the town or city grows around a site and the value of all surrounding land is increased. The value of the mill site, however, has not increased for the purpose to which it is put, and it is of no more value for manufacturing purposes than a site in the suburbs, if other things are equal, instead of being in the congested portion of the city. To a purchaser who wanted the plant to run, its value would be no greater than if it were located where land was cheaper and other things equal; but if the whole property were so run down that a purchaser intended to dismantle the concern and get what he could out of it, the land might then be figured at greater value; but this sort of valuation is beyond the scope and purpose of this paper.

Water-Power Plant.—The value of the plant varies extremely with different conditions which govern the first cost, and with the character of the work done. The effect of the head, length of dam, length of canal, distance from canal to river, etc., increase or decrease the cost of construction. Very much better work is done in some places than in others, which increases the value and decreases the depreciation, so that no general rule can be given to cover all cases. The plant must be considered not alone, but in connection with the privilege, each being dependent upon the other, and each affecting the value of the other, as described in the earlier part of this paper.

For the water-wheels themselves, the average life of the wheel is probably about twenty-five years, while the casing might be allowed to outlive two wheels. Iron or steel penstocks, if taken care of, should last probably 100 years, but wooden feeders underground will not last fifty years. Wooden flumes, gates, and racks which are exposed to the weather will last about twenty years. Some wooden dams have lasted a great many years, but they are apt to get washed away in freshets. Stone dams, if properly designed and well built, will last for hundreds of years.

The market value of the wheels would depend somewhat upon their efficiency, independent of their physical conditions; for it might pay to replace them, if water is expensive, by wheels of higher efficiency. The vertical wheels with bevel gears will not produce as much net horse-power per cubic foot of water as the horizontal wheels; and with the horizontal wheels the extra expense and danger of breakage of gears is avoided.

Steam-Power Plant.—The value of the steam-power plant will depend upon its character and its condition; and its condition depends very largely upon the service which it has rendered.

With good water and good care, running about twelve hours a day, the life of a boiler should be about twenty years, or the depreciation five per cent. a year. Slow-speed engines, running ten hours a day, can be estimated as having a life of about twenty-five years, or a depreciation of four per cent. a year. High-speed engines are much shorter lived, and will not average over fifteen years, or a depreciation of about seven per cent. a year; and oftentimes it is greater when run ten hours a day. The depreciation when run twenty to twenty-four hours a day is correspondingly greater. Boiler settings and piping should be included with the boilers, and engine foundations and piping with the engines.

The life of economizers varies with the initial temperature of the entering water from about ten years up to forty.

The proper type of engine to use depends upon the use which can be made of the steam after passing the engine; and if the most economical plant commercially is not installed, the purchaser must make such allowances as will make good to him the difference in running expense over and above what a new plant would cost him to run.

The proper type of engine for mill work has been discussed by the author in a paper read before the Society, vol. x., paper cccxiii.*

If steam is to be used for power exclusively, the compound or triple-expansion engines of proper designs are the most economical, and for mill work the compound is the more common of the two.

If more or less low-pressure steam is required for other purpose than power, this type in a special form can be used to advantage, except in such cases as require nearly or quite the same amount of low-pressure steam as would be exhausted from an engine producing the amount of power required. Such a condition as this might exist where small amounts of power and large amounts of low-pressure steam are required, as in a dye-house or printery, or in case a portion of the power is produced from water, and the other portion from steam, the power of the latter being such as to supply the required amount of exhaust steam for the various purposes to which it is put.

* "On the Use of the Compound Engine for Manufacturing Purposes," vol. x., p. 48.

In such cases as these it would be absurd to add a condensing cylinder to the engine, and then supply the low-pressure steam direct from the boilers, through reducing valves. The proper type to use here would be the simple or compound non-condensing engine.

Between these two extremes, of steam used for power only, and an amount of low-pressure steam used equivalent to the whole amount exhausted from the engine, lie nearly all the cases of ordinary practice.

If an amount of exhaust steam can be constantly used up to about 75 per cent. of the whole amount exhausted from a high-pressure cylinder of a compound condensing engine, the most economical plant to put in would be a special form of compound condensing engine taking this steam from the receiver; but if more than 75 per cent. of the exhaust could be used for heating purposes, then the proper type would be the non-condensing.

If the amount of exhaust steam used were a variable amount, but averaged more than would allow for equal cylinders on a compound engine, the proper type of engine to use would still be the non-condensing. If the average of the variable amount fell below that amount which would allow for equal cylinders on a compound, then the proper type to use would be the compound condensing engine.

There is one advantage of the compound condensing over the non-condensing engine with variable amounts of exhaust steam used; viz., the low-pressure cylinder, being arranged for a variable cut-off, can control the variation, thus making use of all the steam, decreasing the amount used in the high-pressure cylinder, and preventing any wasteful and unpleasant blowing-off of exhaust steam.

The practical limit of the average proportion of exhaust steam which can be used and still employ the compound system, when the quantity required is variable, is when that proportion requires equal cylinders on the compound engine; and this limit is established by the ability to control the steam exhausted from the high-pressure cylinder.

As to the boiler plant, there are several types and forms which, under proper conditions of setting and working, will give almost equally good results. In these days of high pressure, one would not want to pay full price for a plant on which he would be limited with regard to the pressure, provided this were to be cut below the economical point for the particular plant.

Machinery.—The two most important things which determine the market value of machinery are :

First. Its comparative ability to turn out a product in quantity and quality equal to that of the most improved machines.

Second. Its actual condition with respect to wear and tear.

Although a machine may not be worn out, or even may have been run but very little, it may be unprofitable to run, because other machines have been introduced which do so much more or much better work. These machines may be used to advantage in some other concern, and may on this account have more value than scrap. Parts of machines have been improved so that these portions may be changed while leaving a portion of the machine as before; as for example, cotton-spinning spindles, so that depreciation might be applied to a portion of a machine instead of to the machine as a whole.

The depreciation for actual wear and tear will vary with the severity of the work done, speed of the moving parts, the care taken in the running, and the amount laid out in repairs.

It seems to me impossible to separate the depreciation from wear and tear altogether from that due to improvements in arriving at its present value, and it is customary to treat them in a general way, allowing a definite depreciation to cover both.

Any concern which does not lay aside at least 5 per cent. of the total value of its plant if new, and apply the same at intervals towards the renewal and improvements, will find itself at the end of twenty years in a position not able to compete with success with modern equipped concerns, and it will be necessary to make radical changes at great expense, calling for new capital.

It is often stated that there is no depreciation during the first year of running; that the machinery will do better work after it is limbered up and adjusted than when it is set to work. As a matter of fact, depreciation does begin immediately, although not perceptible. After the first year, depreciation is charged sometimes at a uniform rate of 5 per cent. over all the machinery, due allowance being made for any renewal of parts outside of ordinary repairs. I have used in several cases a depreciation of 5 per cent. up to the dressing-room, and 4 per cent. for the dressing-room and beyond. This view has been presented to me by a member of the Society, that after the first year the depreciation should be marked off 5 per cent. to 10 per cent. a year until the value is brought down to one-half the original cost; then to maintain its

value about level for a while, until it becomes apparent that it would soon be profitable to replace the machinery, when the depreciation goes on at a more rapid rate. This method may be proper for a mill to pursue in its own book-keeping, but it is not quite definite enough in making up a valuation for purchase, etc. It is sometimes the case that some of the machinery is older than these rates would allow them to be in existence, but they may be still there, perhaps for the same reason that the bridge remained which the engineer had figured could not hold up its load. When asked how he explained the fact that it did stand up, he said that the only reason that he could give was that it stood from force of habit. Some machines remain and do work long after it would be profitable to replace them. The value of such machinery to a purchaser is practically nothing, except that it may complete the organization of the mill and allow it to run until it can be replaced by new machinery.

If a sinking fund is created for replacing the machinery, 3 per cent. of the cost would replace it in twenty-four years. There is usually some value to machinery in a mill, even if the property were to be dismantled; but old machinery has no value except for scrap, which is very small, as the cost of taking down is about as much as the value of the scrap.

Shafting, Belting, and Piping.—In an ordinary white mill it is known approximately how much these items should amount to if new. It is possible that more than is actually needed to do the work has been installed, and although the cost may have been more, the value would be no greater than if the proper amount required for a modern mill had been installed. In fact, it may be a detriment to the mill to have more shafting and belting than is required to transmit the power in a well-designed mill, inasmuch as more power is required to drive the mill than would be required with a more simple arrangement.

In a mill which is not a plain mill, the safest way is to make a schedule of all shafting, belting, and piping, and to make an examination to see if they are of the proper size and strength, or if they will require replacing, and to see if the bearings for shafting are such as to produce a minimum of friction and maximum economy of oil, and to see if it is worn. With belting, if a mill has been running for some time, it is customary to place its value at one-half the cost if new, for the machine belts are being renewed occasionally. With piping the examination should be

made to see if the steam pipes are proper for the most economical method of heating, or if they would have to be replaced, and if the pipes for hydrants and sprinklers themselves are such as would be approved by the factory insurance companies, or would have to be replaced, and to see what the condition of the pipe is. It should also be noted if the steam pipes are properly covered to prevent radiation.

Supplies.—It is also known about how much is required to equip a new mill with supplies, but probably the safest way to put a valuation upon these is to make a schedule and note the general condition. It is customary to call the value of supplies one-half their cost new, as they are constantly being renewed, and that is probably as good an average value as could be given for a mill which had run for some years.

In most cases it would not be necessary to schedule shafting, belting, piping, and supplies, but it would be near enough, and within the limits of error on the larger items of value to treat them in a general way.

The Mill as a Going Concern.—There is a special value attached to a mill which is running and in which the purchaser might immediately commence work. There is considerable expense incurred in starting up a mill which is idle, and a large amount of expense in building, equipping, and organizing a new mill, which is not fully realized until paid for. The purchaser is able to begin immediately to manufacture and to realize a profit in good time. All of these things are in favor of an existing plant. There is also the advantage of investing less capital at the start, and if the arrangement and organization are such as may be improved and modernized, these improvements can be paid for out of the earnings instead of from the capital. On the other hand, if the capital can be obtained, it may be wise to be liberal in its expenditure and to begin as quickly as possible to reap the full benefit of the new and up-to-date plant.

A concern which is doing a good business and has an established reputation for making desirable goods, whose trade marks and tickets give the goods an advantage over others not so well known, has an additional value above that of its material value, which must be considered. This advantage may be only transient, and will exist only so long as people can be made to believe that these goods are better than others.

If the valuation of the plant has been very conservative on the

books of the company, and the depreciation has been liberal, it is probable that the actual value of the plant is more than that shown on the books, and a re-valuation at the time of sale may be very desirable.

VALUATION FOR BONDING OR RAISING MONEY.

This value should be based upon the market value, but no more money should be borrowed or loaned than the amount which the property would bring at a forced sale, and this value is likely to be considerably less than the market value.

VALUATION FOR RENTAL.

About the only portions of a plant which are leased are the land and buildings and the power plant. More often this is limited to a portion of a building with power and heat furnished. In nearly all cases the lessee furnishes his own machinery.

The problem which presents itself to the lessee is whether it is cheaper for him to build, if he has the capital or can borrow it, and maintain a plant of his own, or pay for rent and power, which requires a smaller expenditure of capital and less care, and affords an opportunity of testing the desirability of continuing a business or not, without so much chance for loss.

The problem which the owner has to solve is to get enough rent to cover all the fixed and other charges against the plant, and to receive a net return as interest on his investment which shall be satisfactory. The gross income must be large enough to cover the occasional loss of rent when portions are not occupied, and possible loss of a small amount by non-payment of rent.

Buildings and Appliances.—Property intended for this purpose should be built subtantially, but with no outlay above what is necessary to provide a convenient and suitable place to work; for the lessee cannot afford and will not pay rent to cover the charges against a very expensive plant when other places may be obtained at a cheaper rent. The same principles which govern the value of a building for sale, with reference to light and convenience of working, determine its rental value. The convenience of side tracks for receiving and delivering goods, of hoists or elevators for handling goods, the size and arrangement of buildings or rooms for the convenient and rapid progress of the work, all increase its rental value, and they save so much to the lessee.

The age of the buildings does not affect the rental value appreciably if the condition is good and the accommodations equal to a modern building, for the lessee is not the one who must make the renewal at the end of its life. If, however, the lessee is, as a part of his rent, to make all the necessary repairs, the age might have some effect upon the rental value.

Power.—The rental value of a power plant depends upon its character and efficiency to produce power cheaply.

The cost of producing power in small amounts is very much greater than in large amounts, and the amount which the lessee should pay may be obtained in comparison with the cost of producing the amount of power required with a reasonably efficient plant with steam power or by some other means. Thus, supposing the power to be rented is water power and plant, its value can be determined by estimating the cost of producing a uniform power by water power, supplemented by steam power if necessary, and comparing the cost of producing the same amount of power by steam power alone, in each case adding such charges as the lessee is to assume. The difference, if in favor of the water power, will represent the value of the power for the length of time the estimated cost covered.

If the power plant be a steam plant, it is possible that it has no rental value ; that is, it may be so wasteful that it would pay to replace or change parts of it to bring it into an economical state. If it is an economical plant, and is to be run by the lessee, he should pay such rent as will cover depreciation and a fair rate of interest, and assume repairs, insurance, and taxes, or pay enough rent to cover them.

In the same way, if power is sold the lessee, the proper amount to pay per horse-power per year will vary with the amount which he requires.

The problem of a fair price to be paid for water to a water company which owns and operates the water rights, and leases water to persons or corporations who use it in their wheels, and power plants connected therewith, is not an uncommon one.

This subject has been treated by the writer in a paper on the "Cost of Steam and Water Power," which may be found in the *Transactions* of the American Society of Mechanical Engineers, vol. xi., p. 108, paper cccl x.

In that paper the costs of power in large amounts were compared. Since the time of writing, the cost of plants and the

charges for water have changed somewhat, but the comparative results given are not far from correct for the locations under consideration.

As the amounts of power are smaller, the cost of producing it is larger, and therefore a larger price per horse-power per year must be paid.

The charges for small amounts of power seem to vary from fifty dollars to one hundred dollars per horse-power per year; but each case should receive its careful attention.

Sources of Power.—There are now more sources of power than there were a few years ago. In cities of fair size electric power can be had, which is very convenient and requires very little care. Where gas is reasonable the gas engine can be used with a good deal of satisfaction, especially where the work to be done is intermittent. Gasoline and ôil engines are now used with satisfaction. All of these sources are measures of value, and the one which presents the most advantages with the least cost is the one to adopt, if not tied down, or is the standard on which to estimate other values.

With the use of the steam engine the exhaust can often be used. for other purposes, and thus the expense to power be reduced.

Land.—The rental value of land for certain purposes of manufacture cannot be more than other land equally adapted to the same purpose, unless it has some peculiar advantage of location, such as convenience to railroads, nearness to other mills to be supplied with the product of this mill.

VALUATION FOR TAXES.

Taxable Value.—The Public Statutes of Massachusetts, Chap. 11, Art. 45, state that the assessors shall make a fair cash valuation of all the estate, real and personal, subject to taxation therein. We have already discussed the general and broad items which enter into the market value—of location, with its varying conditions of labor, cost of transportation, cost of power, etc. It seems as though this definition of the cash value as the taxable value did not intend that assessors should consider the plant in the same light that a purchaser would, for the reason that the earnings cannot be included in the assessor's investigation, while they are the all important item to the purchaser.

The average assessor knows but little about the physical qualities, to say nothing of going into the estimate of all the items

which make a mill more or less profitable than other mills located elsewhere.

It is not at all improbable that some mills which are running at a loss, or making a slight profit, would be better off to abandon their present site and move their machinery to some more favorable location.

It may have been that when such a ruling was made the choice of locations was not as wide as now, and that it was intended not to consider such broad questions as must be considered by a purchaser, and which to him might render a property of no value to purchase, and yet it might represent a large amount of property.

It would seem, therefore, that in considering the taxable value of a mill, the assessors must ignore the broad questions of labor, location, transportation, etc., and confine themselves to the physical condition of the plant existing at a certain place, which place is assumed to be advantageous to the carrying on of the business. Even in this limited consideration they cannot be as severe upon the plant as a purchaser would be.

For example, suppose that the looms in a mill are old, and so constructed as not to be able to run at anything near the speed and production of modern looms, and that the price of weaving is consequently so much higher than on modern looms as to wipe out what would otherwise be a fair profit on the goods. A purchaser taking this into consideration would say that the looms were of no value; but, unfortunately, they are in the mill, and if the company prefers to keep them, they are taxable property, and the company is unfortunate which possesses much of such property to be taxed.

Reduction in Cost of Construction.—The cost of construction and machinery has been considerably reduced in the last few years. The old high and narrow mills have given way to wider mills of a less number of stories. The walls and foundations are very large items in the cost of construction, as they cost nearly as much for a narrow mill per foot of length as for a wide one, and even more, considering the less thickness and size of foundations required for the lower mill. The cost per square foot of floor area on this account is largely diminished. The cost of materials has also been reduced, and contractors figure much more closely than formerly.

Waste Room.—With wide mills and more area on a floor there

is a less percentage of the room occupied by alleys and spare floor. And with modern machinery less space per spindle or loom, including all the machinery under one unit of spindle or loom, is required, and a greater production is made per spindle or loom.

Relative Cost of Construction and Equipment.—A consideration of all these items will show why the total cost of construction and equipment, per unit of measure the spindle, is less now than formerly, and why valuations made on the same unit in the past may need reduction at the present time. The cost per pound or yard of production is less than that per spindle in comparison with former cost.

Depreciation.—No mill will have the value of its machinery and buildings after a few years of operation equal to what it is new; for depreciation, although not visible, begins almost immediately, and no matter how much care is taken with repairs and renewals, the value of the plant is not that of a new plant. Depreciation must be considered in the same way as for determining the market value. For this reason the valuation in some places is placed low to cover the lessening in values.

Poor Light.—If the mill buildings are radically wrong for light, owing to their antiquated construction, thus requiring artificial light, their value is lessened. Their selling value is lessened if, since their construction properly, other buildings have been attached, thus shutting out the light. This should receive attention from the purchaser. How far the assessors should go in this matter is doubtful.

Land.—The value of the land where restrictions are placed upon it in connection with water power is a nominal sum, and the burden of taxes might be great if the values were placed as high as adjacent land used for other purposes and unrestricted. It is of no more value for manufacturing purposes than a lot in an open field, instead of being located perhaps in the congested portion of a city. The valuation should be moderate in order not to make the tax too great in proportion to the purpose to which it is put.

Steam Plant.—The value of the steam plant should depend upon its age and condition; but I do not see how the assessors can pay any attention to its economical working. If the owners choose to run an uneconomical plant, whose cost is not quite, but nearly, as great as an economical one, that has no bearing upon

its value for taxes. If, however, it is necessary to go to great expense, for instance in foundations for engines, boilers, and chimney, owing to bad soil to build upon, or to build an extraordinarily long smoke flue, the taxable value should be no more than if these extraordinary expenditures had not been required; for the return is no more, and the market value is no more, than that of a much more simple plant.

Water Power.—The tax value of a water-power privilege should be ascertained in comparison with the cost of steam power produced in the most economical method at any convenient location where coal is cheap, or by comparison with the cost of other water power favorably located. Unless this is done, false values will be obtained. If the value of the water power varied directly as the cost of fuel, then the farther from a railroad the power is located, and the more it costs to haul coal to it, the more valuable would be the power. If raw material is to be brought to the mill and finished product to be taken away, it is a self-evident fact that the nearer the railroad or sea-port the mill can be located the more valuable the power which drives it.

All the other items before mentioned which go into the value of a water power should be considered.

Shafting and Belting.—The tax value of shafting, belting, and piping should depend upon the present cost of the proper amount of the same to do the work and upon its physical condition. The fact that much more has been installed, owing to peculiar and perhaps unfortunate circumstances, does not add to its value; in fact, it is a detriment to have more property to care for than is absolutely necessary to do the work properly.

Stock.—In Massachusetts the stock which is in the raw state or in the process of manufacture, and finished product which may be on hand in a corporation, are not taxable property. In a private plant this is taxable. This fact will account very largely for the wide difference in the schedule of valuation prepared for taxes and insurance, as all the stock of whatever kind must be insured. In a corporation the stock in trade is taxed indirectly by the State as the excess of the selling price of the capital stock above the valuation of the real estate.

VALUATION FOR INSURANCE AND ADJUSTMENT OF FIRE LOSSES.

Theory of Valuation.—The standard insurance policy adopted by most of the States contains these words: "This company

shall not be liable beyond the actual cash value of the property at the time any loss or damage occurs, and the loss or damage shall be obtained or estimated according to such actual cash value, with proper deduction for depreciation, however caused, and shall in no event exceed what it would cost the insurer to repair or replace the same with material of like kind and quality."

This sort of valuation is more liberal than any which has been so far discussed. Its theory is that if any loss occurs, the insurance paid shall be sufficient to replace the portion lost, in exactly the same manner as it was before, less a fair amount for the depreciation of the property from age. No depreciation, to my knowledge, however, is allowed for items which reduce the value, as lack of light, inconvenience of arrangement, character of the construction, the fact that a machine may not be economical in its working, or that the steam plant may be an uneconomical one, although such consideration is contemplated in the first portion of the statement quoted. For this reason it is sometimes the case that, if a concern is completely wiped out of existence, after the effect of the first blow is over and the property is rebuilt on new lines, it is vastly better off than before the loss.

One Remedy for Bad Organization.—The story is told of a man who was sent a few years ago to make an examination of a mill in order to see if anything could be done to make its running more successful by reorganization. His examination was brief and his report still briefer; it was to the effect that the only thing which could do any good was a first-class fire. This mill was afterwards sold in open market. Its selling price was very much less than it was taxed or insured for.

Adjustment.—The adjustment of fire loss is usually made upon the basis above stated, that the sum paid should be sufficient to replace new the burned or injured property in the same manner as it existed previous to the fire, less a fair depreciation for age. As it is almost impossible, even by very careful examination, to consider every item of loss, and as the owner is subjected to many losses which are not covered by the insurance, it is the policy of many of the factory insurance companies to be liberal in their settlements, although they state that nothing will be paid for unless in an inventory to which the assured will make oath as true to the best of his knowledge and belief.

These losses are almost always adjusted amicably and without recourse to law. Sometimes they are determined between the

adjusters of the insurance companies and the owner or manager, and sometimes the insurance companies appoint an adjuster and the mill another adjuster, and these two determine the loss; and if they cannot agree on any item they call in a third party, and the decision of any two of the three is final. These adjusters should be men who are familiar with the value of the property destroyed, and more than one set may be required to cover the various kinds of property. Perhaps one set for buildings, one for machinery, and one for goods and stock. The findings of these adjusters are final and conclusive.

VALUATION FOR PURPOSES OF CONDEMNATION.

It is a rare occurrence that a whole plant is condemned, as have been the various mills located in the proposed basin of the Metropolitan Water Supply at West Boylston. It is not uncommon that a portion or all of a water power is condemned.

As cities and towns increase in population they require from time to time additional water supply. Very often, in order to obtain this supply, water must be taken from running streams which furnish power to concerns situated along their courses, or from ponds which are tributary to such streams. If the riparian owners have a legal right to the use of such water for power or other purposes, it is proper that they should receive compensation for the diversion of the same, if by so doing they are actually injured.

Settlement of Damages.—In the cases of the Metropolitan Water Board several have already been settled by mutual agreement between the mill owners and the Board. This is the proper method of settling these damages, without going to court, which is a very expensive and somewhat tedious process. There is no reason why in the case of total condemnation the matter cannot be adjusted in the same spirit as a fire loss would be adjusted, taking into account, of course, the difference in principles involved.

The trials of these cases are usually interesting, each involving some character different from others. The trials of important cases are sometimes very expensive, requiring the services of skilled and well-known lawyers and expert witnesses on each side. Occasionally such trials are held before a jury, but more often before a commission appointed by the court for each special case or group of cases. The trial by jury seems to me to be very unsatisfactory, inasmuch as the ordinary juryman can have but

little conception of the meaning and value of the testimony of the expert witnesses; and even with a commission it is sometimes difficult for the Board to grasp the meaning and bearing of the testimony. It would seem eminently proper that such a Board should have at least one engineer member who is somewhat familiar with theory and common practice of steam and water power and of the transmission of power, and who has a general idea of the value of property under consideration. One member should be a lawyer and decide the admissibility of testimony and decide on points of law. The third member could very properly be a man of high business ability, whose experience has given him a general knowledge of the values of properties similar to those under consideration.

Damage More than Market Value.—In the case of condemnation the sum to be paid is not the market value of the plant, because this is a sale in which the owner is probably not willing to sell, and the condemning party must pay for various things which have no value to him, and for which he can get no return.

The market value is too small a sum to fix as the damage: it should be more nearly the value for insurance; that is, a sum which will replace the plant new with a fair deduction for depreciation for wear and tear. To this must be added an amount which will cover all expenses incidental to the removal of the plant, reorganization, and getting on a good running basis, and the loss of profits during the time required for making this change. There is a chance for wide variation of opinion on this item, but it would seem that the rate of about 15 per cent. per annum on the capital stock is the least which a prosperous mill should receive for payment of salaries and labor which cannot be stopped, payment of unearned dividends, and for general expenses which go on whether the mill is run or idle.

If a mill is fairly new and well equipped it is not difficult to estimate the value of the land, buildings, and machinery. But if it is old and somewhat run down it is then more difficult to determine its value; and in a case of this sort the condemning party will probably be obliged to pay a sum which makes the sale a fortunate thing for the owners and gives them a chance to reorganize the plant if they see fit, or to sell out at a good profit.

Value of Second-Hand Machinery.—In the sale of second-hand machinery, the number of prospective purchasers is limited to second-hand machinery dealers and to other mills which might

need a few of the machines. Nothing could be realized for the older machinery to speak of. If a machine is practically new, the dealer in second-hand machinery can afford to pay about one-half the original cost; but if it has been used for some time, all that could be realized is about one-half the amount left after depreciation. The dealers cannot afford to pay any more than one-half, because of the chances they are obliged to take in disposing of the machinery, and because of the expense of taking down, boxing, shipping, and storage. The probable number of purchasers for special or fancy goods machinery would be very limited.

Variation in Value.—There is not much chance for a large variation in the value of the land, buildings, and machinery; but there is a chance for a wide variation in the value of any water power which may be condemned, with or without the other portion of the plant.

The value of such water power depends upon all the conditions of flow, fall, etc., mentioned before in determining the market value. If the power be undeveloped, the market value should be the amount of damage. If it be developed and used in connection with other fixed property of value, its value then to the concern so using it depends upon the saving of fuel and other expenses which would be entailed by furnishing the power by some other method.

Electrical Power Development.—Great stress has been laid recently upon the utilization of the undeveloped powers for electrical power and lighting, and of their value for these purposes. There are two very important considerations which are not often mentioned in this relation; one is, that if power is to be let it must be constant, and if lighting is to be done it must be certain that it can be done constantly; hence the necessity of producing a uniform power at the source of supply, and the necessity of having in many cases a supplementary steam plant to accomplish this, with its additional first cost and running cost of the plant. The fixed and running expense of the transmission plant must be added to get the total cost of power to be delivered, with its incidental losses in transmission.

Another consideration in favor of a steam-driven electric plant is its greater elasticity over a water-driven plant. In the latter, when the wheels are at full gate the limit of power is reached, and in most cases large amounts of power are required for short periods of time. This necessitates a large plant in proportion to

the average power required, or the installation of storage batteries, with the increased cost of the same. With a steam plant the boilers and engines can be run very much higher than their rated power for such short periods of time as the summit in the load diagram occupies.

Improved Methods.—In figuring the cost of producing the power diverted, by steam power or some other power, any recognized improved methods should be figured on, even if such methods are not in use in the particular case under consideration; for it is not the fault of the defendant if the plaintiff has a wasteful plant.

Damage Cannot be Greater than Value.—The results which are obtained by the method of the plaintiff are oftentimes several times larger than the value of the entire plant, including water power, land, buildings, and machinery. When such results are obtained they are absurd; for the damage to a portion of a plant cannot be more than the value of the whole property, unless it causes great losses or the ruin of a profitable business—and it would be a rare business which could not adjust itself to another location. When such results are obtained it is a sure sign that the method by which they are obtained is wrong.

When a portion of the power is taken, and the property otherwise left as before, the proportionate amount of damage is greater than if the whole plant were condemned; for in the first instance there must be supplied a substitute power, in some form, for that taken away at an expense governed by local conditions, while in the second instance the concern is free to move to a location where power is cheap.

Proper Measure of Damage.—The proper measure of the damage in all cases is the difference between the value of the property before and after the taking. An engineer who is acquainted with all the conditions in the case should be able to estimate the relative value, if not the market value, before and after the taking, very closely, if all the facts bearing upon the case can be obtained. If the difference in the cost of operation before and after the taking is capitalized at a proper rate per cent. it will represent the damage.

Sometimes only a small portion of the flow is diverted, say one per cent. Off-hand one might say that the damage was one per cent. of the value, but this is not so; for it is not necessary to divert the whole flow to make the power worthless. That point is reached when the cost of producing a constant power with steam

and water power combined is equal to the cost of steam power alone. After this point has been reached there can be no further damage.

When it is necessary to estimate on furnishing a substitute plant to produce power equivalent to that taken away, if the cost of the plant is included in the damages awarded, then no interest on the cost should be allowed ; for the party injured is required to spend no money in making his plant good, and therefore has no interest to pay on the cost. The allowance for depreciation will enable him to renew the plant when it is worn out. If, on the other hand, he is obliged to purchase his own substitute plant, the interest charge should enter into the award for damages.

The sales in the market of water power are the best measure of its value, although they are not frequent, and are oftentimes too remote from any special locality to be of great value for comparison ; but where such data can be obtained, it should be of great assistance in forming conclusions of values of powers of approximately the same characteristics and surroundings.

The method of estimating the damage at a sum which shall maintain forever a substitute power, I think is not right, although we use it. It carries the problem into the unknown future, when business conditions will be very different from the present. No business is ever started with the idea that it is to be maintained forever, and no such unknown elements are ever introduced into its location or organization. A limited time should be fixed as a standard by the courts which the damages are to cover, and in England some such custom has been inaugurated, which fixes this limit.

DISCUSSION.

Mr. Geo. I. Rockwood.—I have read this paper with much interest, and it seems to me to be of great value and of timely importance to engineers who have occasionally to act as expert appraisers of mill properties.

A case occurs to me which I think is not explained in the paper (and with which I happen to know Mr. Main is himself as familiar as I am), which is as follows : Suppose that a corporation is deprived by a city both of its water privilege and of its mill property, the mill being in successful operation at the time of seizure. What is the proper measure of damages to allow the company for the machinery in the mill?

Mr. Main says that the appraisal of the machinery is in all cases dependent upon its condition as determined by inspection, but that that kind of testimony is the most difficult logically to maintain. He would lay stress upon the personal experience of the expert examiner as to what constitutes wear and tear of machinery, and his estimate is to be based upon his judgment, after inspection of the machinery, as to how decrepit and antique it is. But it is an every-day matter that experts on one side of a case differ from those on the other side in reporting upon what they have seen, for the simple reason that the rules of experience in these matters are not, and cannot be, precise.

In a case like the one I have mentioned, where the plant is removed, without the consent of the owners, would not a closer approximation to justice be obtained if the value of the machinery were based on the time it has been operated as compared with its natural life, all things considered? I am aware that all experts would not necessarily agree on what the natural life of the machine is; but whatever the disagreement might be, its effect would be reduced in proportion to the newness of the machinery. Thus, if machines have been run five years and have a natural life of thirty years according to one side, and of only twenty years according to the other side, its present value would be five-sixths its cost in one case and three-quarters in the other, a difference of only one-twelfth or eight per cent. between the valuation one side puts on it as compared with that the other side puts on it; whereas, the disagreement as to the length of its natural life is in the ratio of two to three. If, on inspection, the machinery is in any case actually broken, extra allowance can then be made for such cases. Of course such a value is not the whole value of the machinery, as Mr. Main has shown. The cost of transportation and erection must be added thereto, this cost being depreciated in the same ratio as the present cost of the machinery is depreciated.

Mr. C. J. H. Woodbury.—In fixing upon the valuation of machinery in a mill to be seized for some public work or for any other reason, people are apt to fall into the difficulty of going too much into details and not enough into appraisal of the system as a whole. The valuation of this tool or that machine or some fixture by itself in an establishment devoted to the making of specialties covered by patents may be worth so much old junk, but as a part of a whole system of manufacture may be of great value.

The natural life of machinery, it must be remembered, is not wholly a question of the resistance to wear and tear, but it is subject at times to the greater hazard of depreciation from subsequent inventions. After the Border City mill fire the treasurer wired George H. Corliss that the underwriters wanted to discount ten per cent. from the cost of an engine which Mr. Corliss had built only the previous year, and wanted him to come on and defend the price of his engine which had only been used for a year, before the commission that was trying to adjust the loss. Mr. Corliss wired back congratulating him on the small amount of the discount. After the whole adjustment was effected and the matter was all over Mr. Corliss said to me: "In that year I had made other inventions which had depreciated the value of my past work, and therefore if that man was to expend the same amount of money on an engine of this kind he could have got a great deal better engine." Those of you who knew Mr. Corliss and his characteristics can well appreciate the unction which he would give to such a statement. A good many years ago, when George Draper was engaged on the development of the spinning frame for spinning filling yarn, I was in a small private shop where it was working very well. Turning to me he said: "When this machine is done the mules in the cotton mills will be thrown out of the window down a chute because they are not worth the labor to take them down stairs." While as a matter of fact Mr. Draper's anticipations were not so fully realized, yet on certain classes of cotton yarn it did depreciate the value of the mule. It stopped the production of any more and it did cause a depreciation of a great many cotton mills. There is a book on the subject of the depreciation of machinery by Ewing Matheson, an Englishman. The questions involved in the valuations of water powers seized by a city, was gone over very thoroughly by General Butler, as counsel for the city of Boston, in what are known as the Sudbury River cases, in which he introduced, I believe, to American practice for the first time, a great many English judicial rulings on the subject, which were accepted by the commission and have passed into American practice.

Mr. Main.—What Mr. Rockwood says is about right, that you can estimate the value of the machinery by considering the depreciation in a general way about as nearly as in any other way. I think, however, that an examination of the machinery should be made in order to be sure that the depreciation has not been more

rapid than would ordinarily be expected, through excessive speeds or severe work, or longer hours run than usual, or by negligence.

The inability to separate the depreciation from wear and tear and from that due to improvements as mentioned by Mr. Woodbury is spoken of in the paper.

DCCLX.*

MULTIPLE-CYLINDER STEAM ENGINES.—EFFECTS OF VARIATION OF PROPORTIONS AND VARIABLE LOADS.

BY ROBERT H. THURSTON AND LOUIS L. BRINSMADE.
(Member and Past President.) (Junior Member of the Society.)

THE following paper is intended to exhibit the results of an experimental investigation of the relative efficiencies, with varying loads, of the ordinary high-pressure triple-expansion engine, of the compound of usual proportions at similar pressures, and of an intermediate type, already somewhat familiar to the engineering world, through the enterprise of a member of this Society mainly, in which the high-pressure element of the compound engine is made exceptionally small; the effect being, practically, that which would be produced by the suppression of the intermediate cylinder of the usual construction of the triple-expansion machine. The machines employed in this research were, in fact, the available combinations of the largest of the triple-expansion "experimental engines" of Sibley College, and the combinations adopted were:

1. The triple-expansion engine in its usual condition.
2. The intermediate and the high pressure elements combined to make a compound engine of usual proportions—three to one.
3. The low and the high pressure elements combined to produce a compound of the peculiar sort above mentioned—seven to one.

The subject here taken up for study and experimental investigation was first brought into view by the remarkable results reported by Mr. Rockwood to the American Society of Mechanical Engineers, as given by test of singularly proportioned engines, in which the total expansion was that made appropriate to pressures for which triple-expansion engines were customarily used, where great economy was sought, and yet in which he

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* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

adopted a compound system having an abnormally small high-pressure cylinder. The engine was thus very similar in its general arrangement and proportions to a triple-expansion engine with the intermediate cylinder omitted; the exhaust from the high-pressure cylinder passing directly into the low-pressure element, an intermediate receiver being employed of suitable dimensions to give a clean drop and unobjectionable fluctuation of pressures. The economy reported for this case was both unexpected and unprecedented. The following study of the general case will show, at least in part, how this unexpected and singular result came about.

The characteristic feature of this new idea in steam-distribution was a large "drop" between cylinders; but "drop" has never been regarded as a desirable feature in itself, either practically or thermodynamically, and it is interesting to trace out those phenomena and conditions which have here made such a feature a source of advantage. It will further be interesting to see that the thermodynamic case, practically and theoretically, aside from the finance of the matter, conforms to our earlier ideas of the essentials of maximum efficiency.

The *Transactions* of the American Society of Mechanical Engineers for the year 1892, vol. xiii., contain the first account of the results of experimental investigation of the relative value of the peculiar form of compound engine which it is the purpose of this paper to discuss.*

The engine there described was a triple-expansion engine, built from the designs of Mr. Rockwood for the Merrick Thread Co., of Holyoke, Mass. The dimensions were 12, 16, and $24\frac{3}{32}$ inches diameters of cylinder, 36 inches stroke of piston for the high and intermediate cylinders, and 48 inches for the low-pressure element. Receivers were placed between the cylinders, and the cylinders and receivers were jacketed. The machine was rated at 175 horse-power. A separator was used at the engine and returned the condensed and entrapped water to the boiler through a "steam-loop."

The results of test were reported as giving from 12.67 to 13.06 pounds of feed-water per indicated horse-power per hour, with steam at 142 pounds by gauge. The best figure was given when developing 199 horse-power. When the intermedi-

* "Two-cylinder *vs.* Multi-cylinder Engines," by Messrs. Green and Rockwood, presented at the San Francisco meeting, May, 1892, p. 647.

ate cylinder was thrown out of action, the best figure was 12.76 and when developing 180 horse-power. The conclusion was apparently justified that the two forms of engine were of practically equal efficiency. The conclusion might further have been reached that, when costs are considered, the compound, as here proportioned, was the better of the two styles of engine. Still another conclusion would seem to be by this experiment fully justified: that the new system of proportioning the compound engine is decidedly the better where loads are in any considerable degree variable, as giving better opportunity to meet the demand for variable power with least sacrifice of thermodynamic and engine efficiency.

In the discussion of this paper it was remarked by Mr. Cooper that "if two cylinders will secure an economy *commercially* equal to that obtained by the use of a greater number, then two cylinders are enough"—a conclusion which is axiomatic but none the less important. The italicized word—the italics are introduced by the writer—is, however, of special importance; since the maximum thermodynamic efficiency and a minimum consumption of heat, steam, and fuel is not, by any means, necessarily coincident with, or even approximate to, the condition of maximum *commercial* economy. The true statement of the engineer's problem is always: What construction and what steam-distribution will give the largest return on the investment in building an engine to supply a specified amount of power?

It is to be further particularly noted that the question which here arises is not at all whether two or three cylinders should be adopted in a stated case, but, and especially, whether, it being decided that, for business reasons, the compound is better than the triple-expansion machine, the two-cylinder compound should have the usual or an exaggerated cylinder ratio. The question is not whether a two-cylinder is better than a three-cylinder series engine, but whether novel proportions are to be adopted with the older type of engine.

A comparison made by Mr. F. W. Dean, of the performance of an engine designed by Leavitt with one designed by Rockwood, the one having a cylinder ratio of four to one, the other of seven to one, later gave rise to further and interesting discussion.*

* *Transactions* A. S. M. E., vol. xvi., No. 619, p. 169, 1895.

The following are the principal data, as collated by the writer, at the time, in discussion of the paper:

CASE OF COMPOUND *vs.* TRIPLE AND HERMAPHRODITE.

ENGINE.	LEAVITT.	ROCKWOOD.	REYNOLDS.
Number cylinders in series	2	2	3
Steam-pressure, absolute	151.6	175.5	135.45
Vacuum, in. mercury	27.75	25.3	27.6
Ratio of expansion	20.40	33 (nom.)	19.55
Revolutions per minute	18.57	76.4	20.31
Length of stroke, ft	10	4	5
Piston speed, per minute, ft	371.5	611.2	203
Cylinder ratio	4	7	1, 3, 7
Drop between cylinders	None	14 lbs.	None
Dry steam, per I. H. P. per hr	12.156	12.84	11.678
Difference favoring Leavitt	0.684 lbs. = 5.3%		
Difference in favor of triple	0.478 lbs. = 4%	1.16 lbs. = 9%	
	a	*b*	*c*
St. cons. reduced to 175 lbs	11.8	12.84	11.16
Comparative effic. on this basis	0.95	0.87	1.00

The table contains, in the last two lines, figures now added to bring into a more perfect comparison the relative economy of the several types of engine. Taking the best performance of the ideal engine as varying as the logarithm of the pressure employed, as also found by experience to be approximately the fact with good engines, the gain to be fairly anticipated by adopting the higher pressure, other things equal, should be such as to give the figures 11.8, 12.84, and 11.16 pounds of feed-water per horse-power per hour, for the three cases respectively. The relative efficiency will then be expressed by the figures 0.95, 0.87, 1.00. The engine of usual type, as a compound, when well designed and built, thus gives a performance within 5 per cent. that of the best known triple-expansion engine; the compound, with exaggerated cylinder ratio, lacks 13 per cent. of the efficiency of the triple-expansion and 7 per cent. that of the standard type of compound. Leavitt's Chestnut Hill engine, for which the figure 11.2 is reported, may be taken as identical with the Reynolds pumping engine in relative efficiency, correction being made for difference in pressures. Were correction made above for differences in ratios of expansion, the result above indicated would have been somewhat more marked, as the engine

of novel proportions has, nominally at least, 65 per cent. higher ratio than its rivals; but, as a considerable part of this apparent expansion ratio measures free expansion without performance of work, the comparison on this basis would not be strictly correct. No correction is attempted for differences in speeds of piston or of revolution, on which score the intermediate type of engine would apparently have a very marked advantage; but, as was long ago pointed out by the writer, where jacketing is adopted successfully, variation of piston speed seems to have little effect on economy.*

The deduction from the above comparison would seem, unquestionably, to be that the long-standard type of multiple-cylinder engine is a more economical machine than that in which the cylinder ratio is exaggerated so greatly as to produce an unusual drop of steam pressure between cylinders and an apparently highly increased expansion ratio. *A priori*, it would seem to be obvious that that engine which, with equal wastes of heat and steam and mechanical energy, in other respects produces the closest approximation to the ideal steam distribution, and which gives the most perfect reproduction of the ideal thermodynamic indicator diagram, would exhibit maximum efficiency. The engines of Leavitt and of Reynolds are designed with the intent of reproducing a specified diagram, as laid down upon the drawing board of the designer, and that diagram is made as nearly ideal as practicable. In the solution of the problem thus set for themselves, these designers have succeeded wonderfully; and this, with their careful provision against internal heat wastes and against excessive engine friction, accounts for their rare success in these engine trials.

But there still remain two important questions undecided:

(1) Are these comparisons fair, as being representative of the best work that each type of engine can perform; and does it follow that the study of the performance of each throughout a wide range of load variation will prove that these conclusions may be accepted as general and as completely settling the relative standing of these machines?

(2) Assuming it to prove to be true that the orthodox system of designing the multiple-cylinder engine, as illustrated by the refined practice of Leavitt and of Reynolds, of Sulzer and of Corliss, and as taught in the text-books and treatises on the

* *Transactions* A. S. M. E., 1881, "Manual Steam Engine," vol. i.

steam engine from a more purely scientific standpoint is right—is it always correct, as judged from the point of view of the purchaser and user of the engine, who counts success by the relation of quantity of work performed to the dollar expended, and not with reference, otherwise than incidentally, to the weight of steam or of fuel demanded per indicated horse-power in the unit of time?

The first of these questions can only be answered after it has become possible to produce a "curve of efficiency" on which may be read the relation of cost to performance throughout the full range, at least, of usual variation of working load, and for each of the machines to be compared. The second must be answered by a study of the costs of power production, with each reduced to the measure of the efficiency of the dollar in each case.

The following pages present an account of such an investigation as is above outlined, in which the compound, the triple, and the intermediate type of engine are compared experimentally, by constructing representatives of each type, by various combinations of the elements of the largest of the triple-expansion experimental engines of the Sibley College laboratories. A compound engine was produced by the combination of the high and intermediate cylinders, in which ordinary proportions were illustrated; a second compound was produced by combination of the high and the low pressure cylinders, in which the peculiarity of greatly exaggerated cylinder ratio was introduced; and the third combination was that of the three cylinders in normal working, and representative of the standard proportions of the ordinary triple-expansion engine. With each arrangement a series of trials was made, from the results of which it became practicable to produce the form of efficiency curve which was sought as the solution of the problem to be attacked. Since, however every steam pressure, for best effect, demands a specific ratio of cylinders and an expansion-ratio peculiar to itself, and since each ratio of expansion adopted, at any constant steam pressure, presumably demands, for best results, some special form and proportion of engine, it remains probable, after all, that absolutely exact and perfect comparison would require more extensive investigation than has been, in this case, as yet practicable. The facts here revealed will simply add to, without completing, our knowledge of the case; while, in the opinion of the writer, the character of the question

will be practically settled as commercial, and not as purely thermodynamic, or, in the sense in which the engineer usually employs that term, economic.

The figures above quoted and tabulated as the results of trials of representative individual cases are assumed by the writer to be acceptable to this degree: that they are in each case so excellent as to permit the deduction that these unexampled data are indicative of the conditions of best effect in each case, so nearly as to justify us in taking the comparison as probably fair for that set of conditions marking the best work of each.

The general dimensions of the engines employed in this investigation are as below:

GENERAL DIMENSIONS OF ENGINES.

	High Pressure.	Intermediate Pressure.	Low Pressure.
Diameter of cylinder, in inches	9	16	24
Length of stroke, in inches	36	36	36
Clearance, per cent.:			
Head	7.74	8.79	9.5
Crank	7.45	8.89	9.2
Clearance, cubic feet:			
Head	0.103	0.376	0.895
Crank	0.092	0.367	0.812
Piston displacement, per stroke, cubic feet:			
Head	1.3291	4.1887	9.4247
Crank	1.2379	4.1204	9.3373
Area piston, in square inches:			
Head	62.62	201.06	452.39
Crank	59.42	197.86	443.19
Fly-wheels, diameter, in feet	10	10	10
Fly-wheels, face, in inches	17	17	17
Fly-wheels, weight, in pounds	6,934	6,938	6,935
Brake-wheels, diameter, in feet	4	4	4
Brake-wheels, face, in inches	10	10	10
Brake-wheels, weight, in pounds	....	....	....
Crank-pin, diameter, in inches	3½	3½	3½
Crank-pin, length, in inches	3½	....	....
Connecting-rods, length, in feet	9	9	9
Main bearings, diameter, in inches	7	7	7
Main bearings, length, in inches	13	13	13
Length of pulley-block bearings, in inches	10½	10½	....
Steam-port dimensions, in inches	⅝x12	1x20	1⅜x28
Exhaust-port dimensions, in inches	1½x12	1¾x20	2½x28
Diameter of steam-valve seats, in inches	3½	5	6½
Diameter of exhaust-valve seats, in inches	3½	5	6½
Thickness of steam space in jackets, in inches	½	$\frac{13}{16}$	¾
Diameter of piston rod, in inches	$2\frac{5}{16}$	$2\frac{5}{16}$	$2\frac{5}{16}$
Diameter of steam inlet, in inches	3	6	6
Diameter of exhaust outlet, in inches	5	5	8
Diameter of crank-pin, in inches	3½	3½	3½

The experiments to be described were performed in the course of the regular, advanced work of the college, under the supervision of its officers, and in accordance with the often described and standard methods adopted for all such work in research in this department. The investigation here to be particularly described was made by Messrs. L. L. Brinsmade and Adelbert Harding, in the course of work for their respective degrees,* and with the aid of volunteer expert assistants where numbers of skilled men were needed in the course of the engine trials. The usual precautions were adopted in the standardization of apparatus and checking of determinations, where more than one process was available. The details of these processes are already familiar to all and need not be here repeated. They will be found described in various papers previously presented to the Society, in which such experimental work is described in detail; which papers are published in earlier volumes of its *Transactions*.

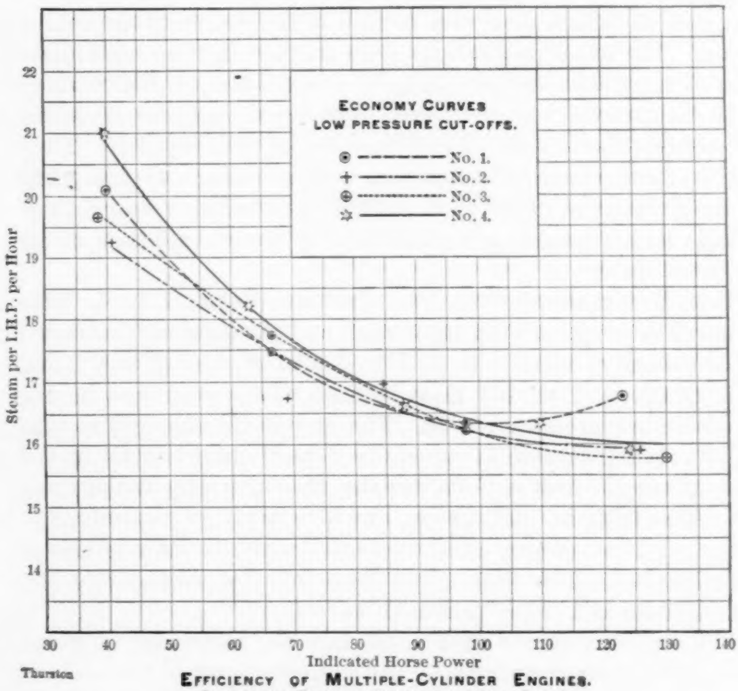
The Experiments with the Cylinder-Ratio, 7 to 1, were planned in advance, with great care, and all tests are indicated alphabetically; tests *A* to *E*, *E* to *I*, *I* to *M*, and *M* to *Q* being four groups, and all the tests in each of these groups having the same low-pressure cut-off. The groups are arranged so that these cut-offs increase in value, the *A*-to-*E* group containing the tests at the shortest cut-offs and the *M*-to-*Q* group at the longest. The tests in each group are also arranged according to indicated horse-power, which increases with the later letters of the alphabet. The data given here are the averages of the general data and of the principal results.

The economy curves in Fig. 39 show the variations in steam consumption for variations in the indicated power for each of the four cut-offs. In No. 1 there is no uncertainty about the maximum point in the curve. Nos. 2 and 3 do not show a distinct maximum; but, from their horizontal drift at the heaviest loads, it would appear that these loads were very near those of maximum economy for those cut-offs. The direction of the

* The theses in which the details of this work are completely presented may be consulted at the library of Sibley College, Cornell University, where they are preserved with a number of others bearing more or less directly upon the same problem and upon the effects of variation of working conditions upon the various experimental engines of the college, including all the combinations referred to in this paper.

line at the end of the economy curve for No. 4 would seem to indicate that the point of maximum efficiency for that curve had not been reached.

Fig. 40 shows the variation of B. T. U. per indicated horse-power, with variations in the indicated power for the different low-pressure cut-offs, and gives a very similar set of curves to those shown in Fig. 39. This would be expected from such slight



EFFICIENCY OF MULTIPLE-CYLINDER ENGINES.
COMPOUND ENGINE; CYLINDER-RATIO, 7 TO 1.

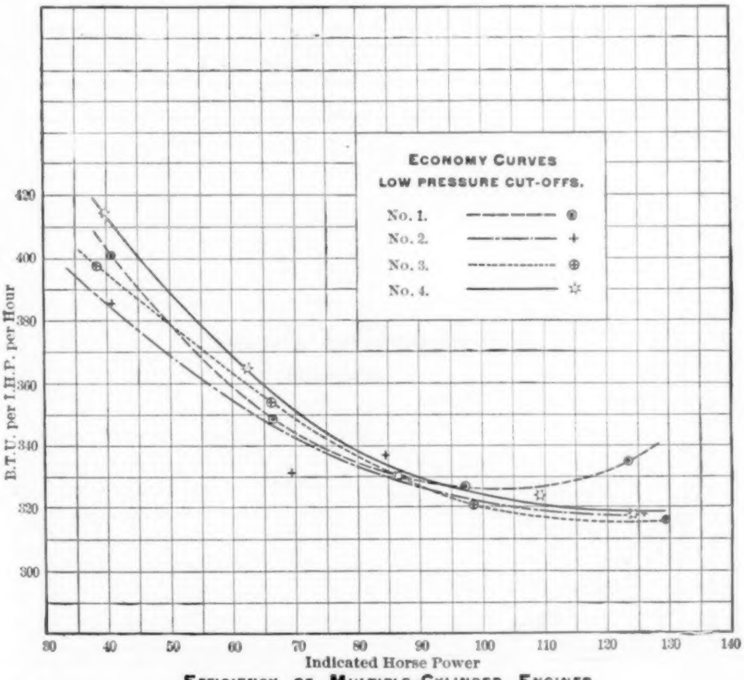
FIG. 39.

variation in the total heat of evaporation as a few pounds variation in the average boiler pressures would produce. They are inserted as affording a more precise method of gauging economy than that by steam consumption.

Logs of the work were prepared from the records of these trials, in such form as was thought most convenient for the purpose, and these logs will be found appended.*

* Appendix A.

The diagram herewith reproduced (Fig. 41) exhibits the method of variation of the pressure-volume expansion line when the engine is given a total ratio of expansion of about 20. The saturation curves for the two cylinders are laid down beside the expansion line of each indicator diagram, and the quality curves superposed show the differences, varying from point to



Efficiency of Multiple-Cylinder Engines.
Compound Engine; Cylinder-Ratio, 7 to 1.

Fig. 40.

point, measuring the cylinder condensation and the quality of the steam in the engine. In the high-pressure element the quality of the steam at cut-off is seen to be nearly 0.90, dropping at a point slightly beyond to 0.86, and thence rising again until, at the opening of the exhaust valve, it has become substantially the same as at cut-off. In the low-pressure element the effect of drop becomes plainly obvious, the steam entering up to cut-off with a quality exceeding 110—*i.e.*, superheated in that proportion—and immediately falling to unity, and, later,

at a little beyond half-stroke, to 0.92. From this point on it rises steadily and very uniformly to the end of stroke, and is exhausted into the condenser with five per cent., nearly, excess, or superheat. This last condition has been regarded as indicating some waste, as it is usually thought that maximum efficiency is to be secured by so adjusting the working conditions of the

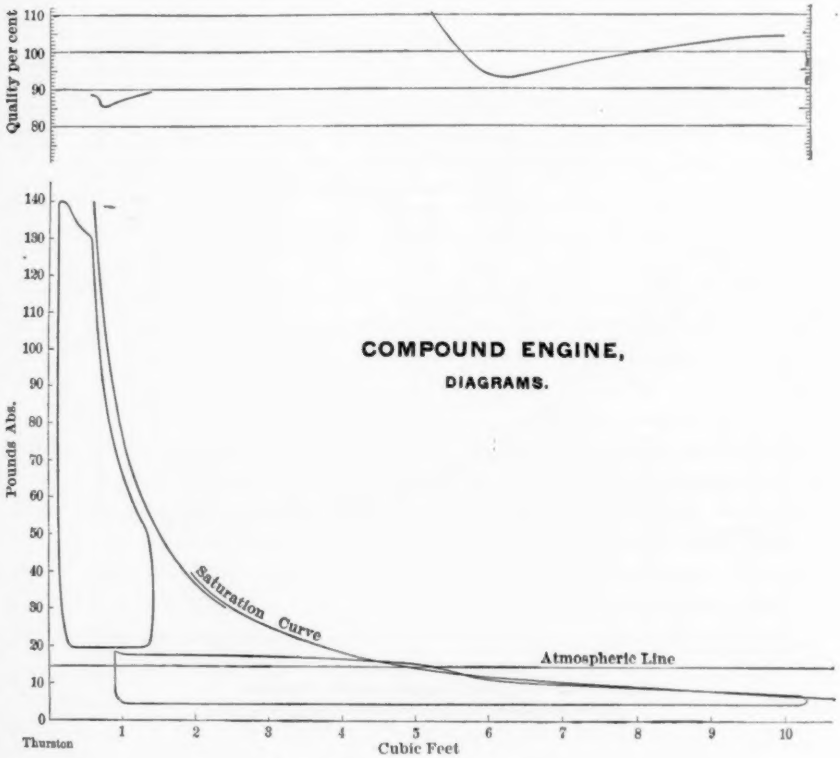


FIG. 41.—(SPECIAL.)

machine as to give dry and saturated steam at exhaust. The influence of a superheated charge during exhaust, however, in reducing the loss of heat from the cylinder wall, is probably measurable, and it is possible that slightly superheated may give higher efficiency than slightly moist steam.

A COMPARISON OF RESULTS with those obtained on the 3-to-1 compound and triple-expansion engines may now be made :

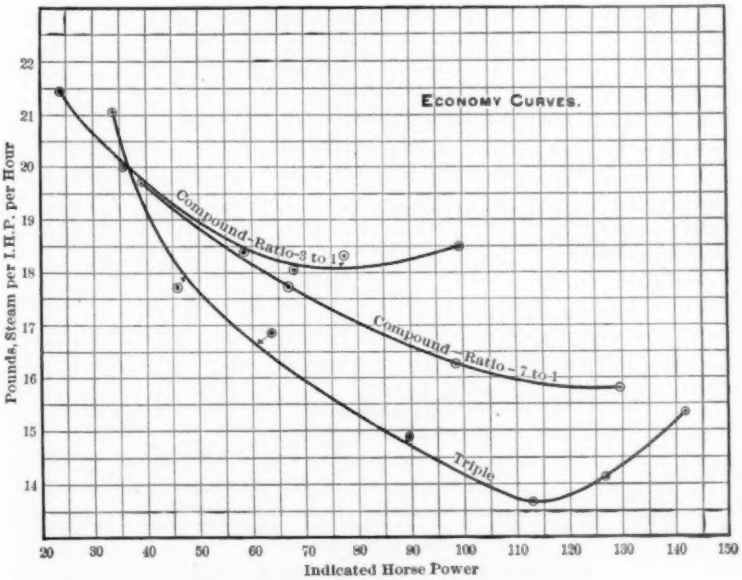
The following data are from experiments on the Sibley

experimental engine, made by H. K. Spencer in 1895, and will serve as a basis of comparison of the results just summarized.

The first set of data was taken from the engine while running with the high-pressure and intermediate cylinders compounded, giving a cylinder ratio of a little over 3 to 1.

The second lot of data are from the same engine, with all three cylinders in use. (Appendix B.)

In both cases everything was jacketed except the low-pressure cylinders, thus giving approximately the same conditions that



EFFICIENCY OF MULTIPLE-CYLINDER ENGINES.

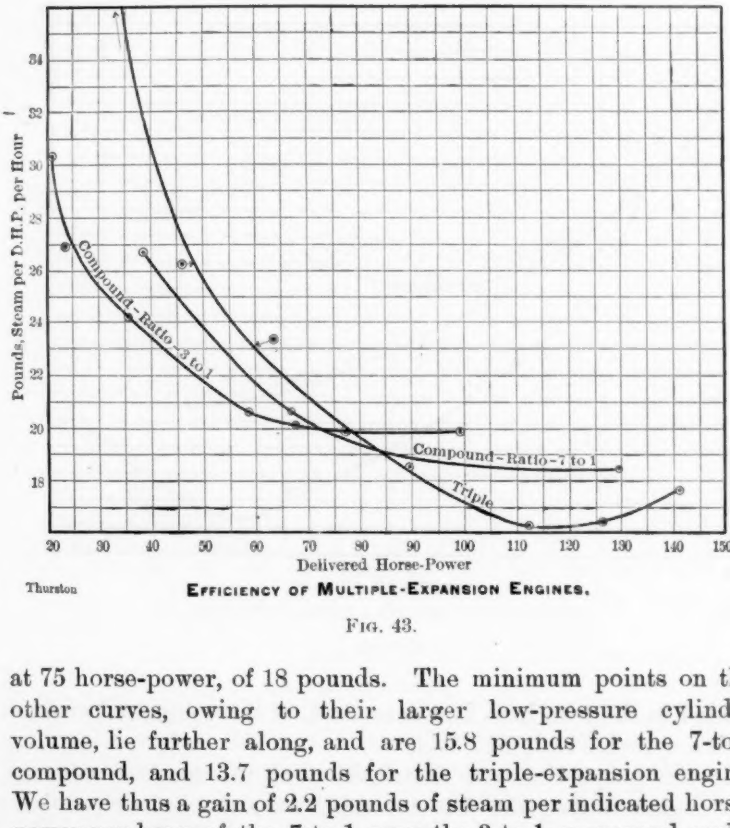
FIG. 42.

existed in the test, here first described, of the compound engine with a cylinder ratio of 7 to 1.

In the proportion and distribution of the receiver volume, the engine during the 3-to-1 compound and triple-expansion tests had an advantage. With the 7-to-1 cylinder ratio the engine had an abnormally large receiver volume, and, in the passage between the receivers, the steam was sent through a considerable length of piping which condensed some steam by radiation.

Curves were plotted from the results of these three sets of experiments thus:

Fig. 42 shows the variation of the steam consumption per *indicated* horse-power, with the increase in load, for the three prescribed sets of conditions. The curves in this figure leave no room for doubt in regard to the relative economy of the three engines. At about 37 horse-power the steam consumption in each case is about the same. The curves then diverge, the 3-to-1 compound reaching a minimum steam consumption,



Efficiency of Multiple-Expansion Engines.

Fig. 43.

at 75 horse-power, of 18 pounds. The minimum points on the other curves, owing to their larger low-pressure cylinder volume, lie further along, and are 15.8 pounds for the 7-to-1 compound, and 13.7 pounds for the triple-expansion engine. We have thus a gain of 2.2 pounds of steam per indicated horse-power per hour of the 7-to-1 over the 3-to-1 compound, and a gain over the former by the triple-expansion engine of 2.1 pounds of steam per indicated horse-power per hour.

Fig. 43 shows the variation in steam for delivered, or dynamometric, horse-power, with varying load for three cases. It

will be noticed that the curves approach each other much more nearly than in the last figure. At the minimum the triple-engine curve exhibits best economy, but it falls off very rapidly, and at 75 horse-power shows a greater steam consumption than either of the others.

The 7-to-1 curve also crosses the 3-to-1 curve a little below this point. The reason for this is probably the friction of the extra bearings and the weight of the intermediate valve rods, which the construction of the engine made it impossible to avoid for the tests on the 7-to-1 compound. Otherwise there are about the same number of working parts as in the 3-to-1 compound, and there should be very nearly the same per cent. loss by friction.

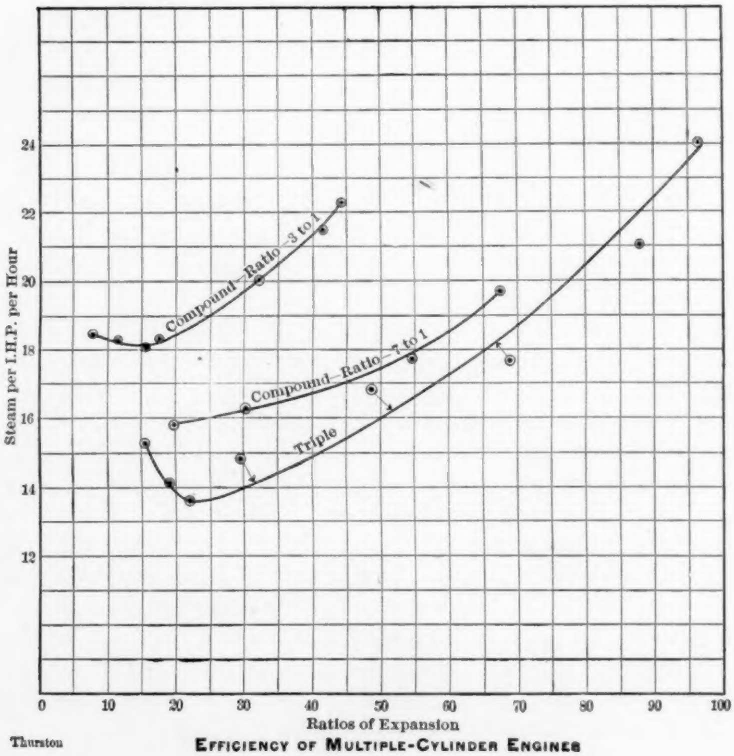
The minimum points in these curves are 18.9 for the 3-to-1, 18.1 for the 7-to-1, and 17.1 for the triple expansion, showing a gain on the triple over the curves of Fig. 42 of one pound of steam by the 7-to-1 compound, and a little over two pounds by the 3-to-1 compound.

Fig. 44, perhaps the most instructive of the series, shows the variation in the steam used per indicated horse-power per hour, with the ratio of expansion for the three cases. In the 3-to-1 compound and the triple the most economical ratios are apparent—about 12 for the 3-to-1 compound, and 21 for the triple. Assuming the most economical expansion in any one cylinder for a continuous expansion line to be 3, this would make, in the case of the 3-to-1 compound, a total expansion of 9, showing that in the above case there was comparatively little expansion in the receiver. In the case of the triple the division of the expansion ratio is taken from the most economical card, which is as follows: 2.7 in the high-pressure cylinder, 3.15 in the intermediate, and 2.16 in the low-pressure cylinder, making a total of 18.5 as the expansion ratio, which makes the expansion line practically continuous.

In the 7-to-1 compound the best ratio of expansion is beyond the limits of the curve, but would apparently be in the neighborhood of 17. The distribution of the expansion, however, at the most economical point obtained was 2.7 in the high-pressure cylinder; 2.21 in the low-pressure cylinder, leaving 2.85 as the expansion ratio in the receiver. This division is very nearly the same as in the triple-expansion engine, the receiver taking the place of the intermediate cylinder.

To show more clearly the location of the gains in economy of

the triple-expansion engine over the 7-to-1 compound, Fig. 45 was constructed from the most economical tests on both engines. As these two tests had nearly the same high-pressure cut-off, it is easy to trace the action of the steam throughout the stroke, and the gains and losses of the two systems are made very evident.



EFFICIENCY OF MULTIPLE-CYLINDER ENGINES

FIG. 44.

These cards show a loss in area due to drop, and a gain in the clearance spaces and in the expansion line of the low-pressure cylinder, although the latter gain is probably increased by the poor vacuum in the 7-to-1 compound. The diagram also serves to show the respective amounts of work obtained by an increase in the steam pressure, and by an increase in the vacuum; the area at the top representing the work due to an increase in steam pressure of over 10 pounds, while the area at the bottom

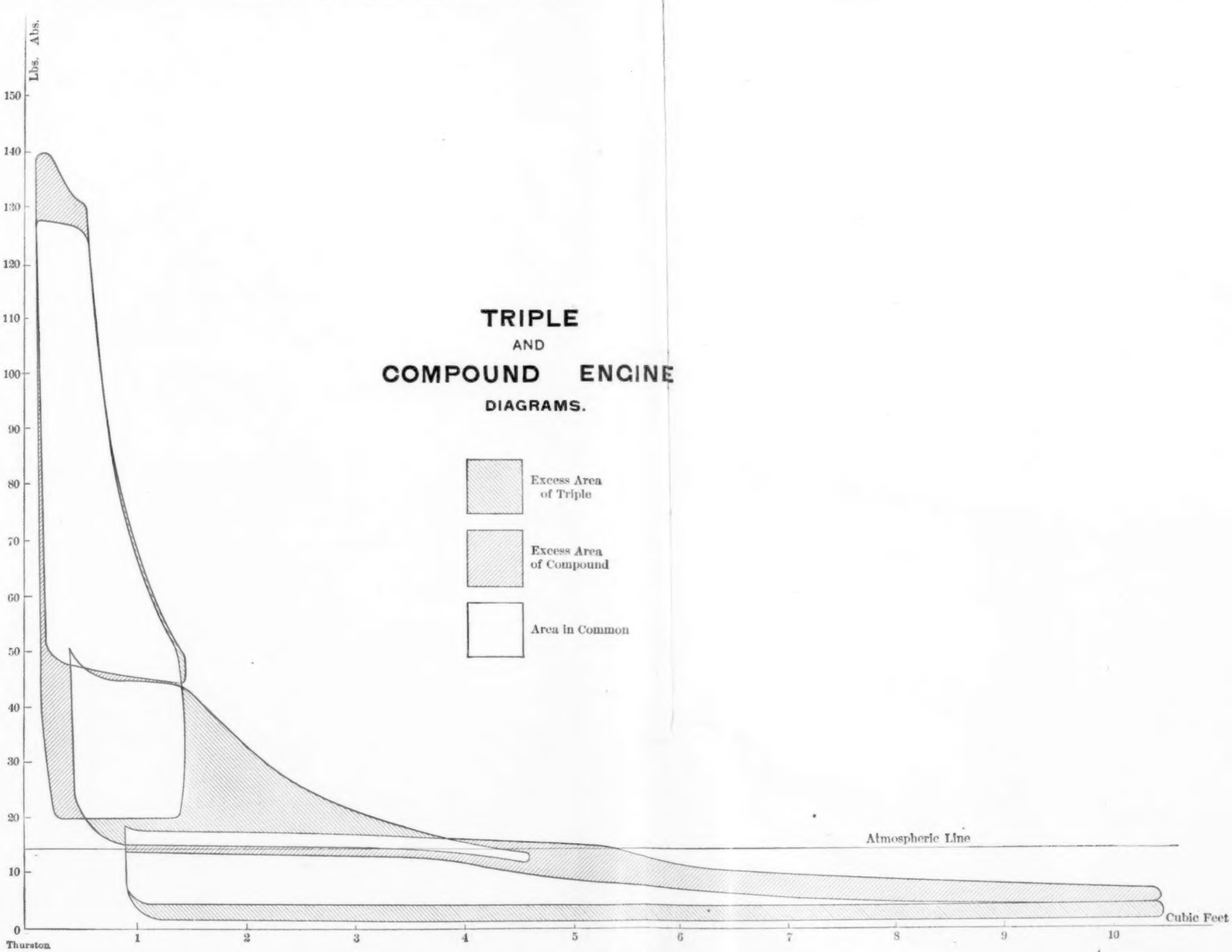

Lbs. Abs.
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
TRIPLE
AND
COMPOUND ENGINE
DIAGRAMS.
Excess Area of Triple
Excess Area of Compound
Area in Common
Atmospheric Line
Cubic Feet
Thurston
1
2
3
4
5
6
7
8
9
10

Fig. 45.

represents the work obtained by about two pounds better vacuum.

The following table shows the conditions during the most efficient periods of test of the three systems:

COMPARISON OF THE MOST ECONOMICAL TRIALS.

	Triple.	7-to-1 Compound.	3-to-1 Compound.
Boiler gauge	119.1	115	117.5
Revolutions per minute	84.95	87.65	85.52
Vacuum in inches of mercury	24.3	22.84	22.7
Condensed steam in pounds	1,205	1,753.7	1,030
Total jacket-water	335.4	316.7	190.97
Total steam used	1,540.3	2,070.4	1,221.2
Total I. H. P.	112.65	129.97	67.7
Distribution of work between cylinders, H. P. = 1	I. C. = 1 L. P. C. = 1	1.29	.635
Mechanical efficiency	84.1	86.6	90
Steam per I. H. P. per hour	13.68	15.8	18.03
B. T. U., ditto	16,400	18,900	21,600
Number of expansions	22	18.89	15.45
Steam per I. H. P. corrected to a vacuum of 24.3 inches mercury	13.68	15.1	17.3

It will be noticed that in the triple-expansion tests both the vacuum and the boiler pressure are better than in either of the others. Between the most economical test of the triple and the most economical test of the 7-to-1 compound, there is a difference of an inch and a half of mercury in the vacuum, and of four pounds in the boiler pressure. The column showing the three tests reduced to a common back pressure was obtained by increasing or diminishing the mean effective pressure in the low-pressure cylinder of each by the amount each varied in back pressure from that of the required mean. In this case the mean was taken as the back pressure in the triple-expansion test. This correction brings the triple and 7-to-1 compound nearer together, but we shall still have a difference in steam consumption of 1.48 pounds of steam per horse-power per hour between the triple and the 7-to-1 compound, and a difference of 2.1 pounds between the latter and the compound with the 3-to-1 ratio of cylinder volumes.

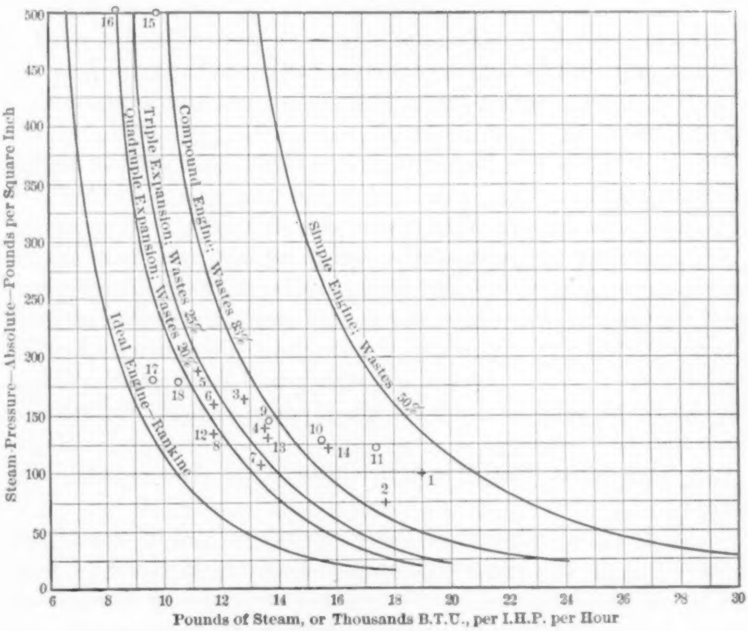
In the Appendix will be found the collected and essential data taken out of the several logs of the various engine trials, so arranged as to permit easy comparison and prompt deduction of conclusions.*

* See Appendix B, page 186.

To show still more clearly, and by an entirely different method, the real position of the three machines here reported upon, as related to the record-breaking engines to date, and to each other as well, Fig. 46 is introduced. On this diagram are entered the records of famous engines to date, showing their standing when gauged by the location of their reported economies to that of the ideal thermodynamic engine whose efficiency curve is given at the extreme left as that of the "ideal case." The relative merit of each engine is determined by the approximation of the datum entered on the plate to the ideal efficiency lines adjacent. Thus, it is here at once seen that the observations being entered from the table just presented, the figures fall, respectively, No. 9 between the curves assigned to the compound and to the triple engine of good performance and of large size, No. 10 close upon the curve for the compound, and No. 11 near the curve for the simple engine wasting half the steam supplied. The 3-to-1 compound, thermodynamically considered, gives substantially the same approximation to the ideal as does No. 1, the Sulzer engine, whose performance is there recorded as that of a representative simple engine. The 7-to-1 compound similarly approximates the rank of No. 2, the simple Corliss engine, which latter, in turn, takes rank with the ideal compound very nearly; and the ideal compound, as just seen, gives very nearly the figure actually obtained by the 7-to-1 compound. An earlier performance of the triple-expansion engine No. 4 is seen to approximate more closely the ideal curve for its class. Were these comparatively small engines reproduced on the scale of the larger proportion of the engines giving the results here noted, the wastes would presumably be reduced by such increased size by something like 25 per cent., and the locations Nos. 12, 13, and 14 would represent the relative merits of the three types compared, both as among themselves and as related to the record-breaking engines of the world.

For comparison, also, at extreme pressures, Nos. 15 and 16 are given as those, respectively, for the actual performance of the Sibley College 20 horse-power quadruple-expansion experimental engine, and for that estimated for such an engine reproduced on the scale of the engines given as "record-breakers." To complete the record for comparison, the figures for the steam consumption of two Schmidt superheated-steam engines,

Nos. 17 and 18, are shown, as reported *—9.46 and 10.2 pounds of steam, respectively; but the figures, like those of the quadruple expansion in less degree, are not strictly comparable, and the British thermal units per indicated horse-power giving a higher relative expenditure by 20 per cent. or more, usually corresponding, in fact, to 12 pounds or more of saturated steam,



STEAM ENGINE EFFICIENCIES, 1897.

1-Sulzer-1; 2-Corliss-1; 3-Rockwood-2; 4-Sibley College-3; 5-Leavitt-2;
6-Sulzer-3; 7-Sulzer-2; 8-Reynolds-3; 9-Sibley College-3; 10-7 to 1 Compound-2;
11-3 to 1 Comp.-2; 12-Triple (large scale); 13-7 to 1 Comp.(large); 14-3 to 1 Comp.(large); 15-Sibley College-4;
16-Same (large scale); 17-Schmidt-2 (Superheat.); 18-Ditto.

Thurston

FIG. 46.

are more nearly correct data for comparing with the records of the other engines, in which latter the steam is little, if at all, superheated, at the steam chest. †

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* *Proceedings of the British Institute of Civil Engineers*, March, No. 3,008, vol. cxxviii., 1897.

† This diagram, in slightly different form, was first employed by the writer in a discussion of the paper of Professor Ripper, "On Superheated Steam Engines." *Ibid.* See also *The Electrical Engineer*, January 6, 1897.

THE REQUISITES OF MAXIMUM THERMODYNAMIC EFFICIENCY WITH CONSTANT LOAD are :

(1) A steam distribution approaching most closely the ideal of Carnot; or, assuming the cycle of Rankine to be that in which the machine is constructed to act, the closest possible approximation to the ideal conditions of distribution for that cycle.

(2) As nearly as practicable, a non-conducting cylinder, or its equivalent, a non-heat-transferring working fluid, insuring, approximately, at least, adiabatic action, so far as heat transfers between working fluid and enclosing walls are concerned.

(3) Maximum possible range of pressure and temperature during expansion.

THE REQUISITES FOR MAXIMUM TOTAL EFFICIENCY are the above, together with :

(4) Minimum friction of engine and heat losses.

(5) Limitation of the expansion range by that volume at which the expansion line meets the line, parallel with the back-pressure line, marking the sum of the useless resistance of the machine plus that added quantity which is a fraction of the mean effective pressure equal to the ratio of the steam and heat wastes, internally and externally, due extra thermodynamic causes, to the total steam and heat supply.

THE REQUISITES FOR MAXIMUM COMMERCIAL EFFICIENCY are, further :

(6) Such an adjustment of the proportions and of the steam distribution of the engine that any change would cause a larger loss in the dividend account than would be saved by better conditions in the direction in which improvement was sought.

In detail, in compliance with the above conditions to that extent which best answers the last of these various requirements, and, therefore, which effects the most satisfactory compromise, the form of the cycle must be as nearly that prescribed above as practicable.

This means introduction of the steam invariably at as nearly as practicable boiler pressure ; a sharp cut-off; expansion along as nearly as practicable an adiabatic line, the steam being worked within non-conducting walls, if possible, or in a jacketed cylinder, or as superheated steam, in the actual case of to-day ; expansion terminating at a pressure which is the sum of the friction pressure shown as the total mean pressure of the "friction diagram" of the engine, *plus* the proper allowance for heat

wastes as above; sharp drop from the terminal pressure thus determined to the minimum practicable back pressure; maintenance of that minimum back pressure from exhaust to the point at which compression begins; and, finally, compression as nearly as practicable to boiler pressure.

The "practical" limitation in each case will be found to be at such adjustment that to gain more, ideally, would cost more than the gained power or saved steam would be worth. Too large a steam pipe; costly expedients for sharpening the cut-off corner, or for other approximation to ideal conditions; too low a temperature and pressure in the condenser; such may, either or all, prove expensive methods of gaining higher "duty" of engine.

Whether the engine be simple or multiple-cylinder the designer will seek the closest approximation to the ideal diagram, simple or combined, that he finds likely to give gains more than compensating the costs of securing them. Where the engine is designed to compete for a prescribed high "duty," the pecuniary limitation takes another form, which it is not our province here to consider, and the problem, in design, becomes that of approximating the ideal case in such manner as to attain maximum thermic rather than commercial efficiency.

From either point of view, "drop" between cylinders is evidently not desirable; though, at the point of termination of expansion in the low-pressure cylinder before condensation begins, drop is required, proportioned to the extent of the sum of the quantities: friction and cylinder-condensation wastes, including also, if it exists, leakage. From either point of view, also, compression to boiler pressure, with minimum "dead spaces" and minimum clearance, is requisite. In either class of engine the machine acts as a whole, and is to be treated as if the work at the crank-shaft were performed as indicated in the combined diagram, in the case of the multiple-cylinder engine, precisely as if it were a simple machine.

As seen in Fig. 45, the relative value of this and the orthodox type may be found to depend largely upon their relative clearances. The examination of this point by Dr. Amsler, following Professor Barr, shows clearly that a gain by exaggerated cylinder ratio may be reduced by decreased clearances.

When we have a variable load, the conditions differ not only from those affecting the engine under constant load, but also as

affecting the two classes of engine. The problem for the simple engine becomes in effect the following:

Required, to secure such a design and construction of engine as will permit its operation, under varying loads, in such manner that the work performed shall always be precisely that corresponding, *net*, to the load imposed at the instant, *and also*, at the same time, so that the terminal pressure on the expansion line shall not fall below the "*virtual* back-pressure line," as the writer has sometimes called it, computed as above. This means that when smaller loads are dealt with than that which constitutes the best for the machine as designed, a lowered boiler pressure is better than a shorter cut-off.

The problem for the multiple-cylinder engine becomes quite different from the above, for the reason, as above indicated, that the ratio of volumes of its cylinders is a fixed quantity and cannot be made alterable, as should be done, if practicable, with variable loads. Thus the problem involves the selection of such a ratio as will suit, not the best load of the engine, but that load which must be taken as the probably best mean for the series of variations which are anticipated as characterizing the probable life-action of the engine. The ratio of chosen boiler pressure to selected terminal pressure ordinarily settles the total ratio of expansion and that of the cylinders, and all proportions of the engine for constant load; but this is not true with such variations of load as are daily witnessed in the operation, for example, of the power stations of electric railways. It may, in this case, be found that "drop" is a requisite of best mean performance, whether thermal or commercial, and new relations of expansion in cylinders in series may be best.

But these are not all the new considerations coming in to complicate this question in the practical case of every-day work. It may prove so much cheaper to build, as well as to operate, an engine in which we have the equivalent, practically, of the triple-expansion engine, for example, with the intermediate cylinder cut out, as to make it a better dividend earner than the unmutilated triple-expansion engine. The reduced cost of construction may more than pay for the loss of efficiency, even at its best load, and with variable loads it may prove that the unorthodox form of compound may pay better than either its orthodox competitor or the triple-expansion machine. Such are the still existing problems for the designer.

In conclusion, these comparisons, after making all allowances, show an economy in favor of the triple, when compared to the 7-to-1 compound, of over one pound of steam per horse-power per hour, and a larger gain by the latter when compared to the compound engine of 3-to-1 ratio. The bearing of these results, however, on the relative merits of the three types, is a matter which experiment on one engine and under one set of conditions cannot definitely determine. As tests have been made of the triple-expansion engine under all systems of jacketing, there is no room for improvement in this direction. In the 7-to-1 compound, however, a change in the jackets, and even more probably a change in the size and distribution of the receiver volumes, might reduce, if not nearly bridge over, the gap which at present separates it, so far as steam consumption is concerned, from the triple-expansion engine.

In looking over the water account of both the triple-expansion and the 7-to-1 compound, we find that all the water used by the latter, in excess of the former, passed through the cylinder, and that there is no appreciable difference in the jacket water in either case. This indicates that the waste is internal, and due to either an extra loss by cylinder condensation, to a greater clearance loss, or to a loss coming of incomplete expansion of the steam. That the greatest waste is due to incomplete expansion in the high-pressure cylinder, and that there is a slight gain in the cylinder volume, are both made evident by theory and are clearly indicated on the diagram showing the superposed cards of the engines.

The comparative amount of cylinder condensation in the two engines, and the manner in which this condensation is affected by the drop in pressure between the cylinders, is a matter on which there has been considerable doubt, and on which these tests seem to throw some valuable light.

Owing to the lack of necessary data, the comparison of the quality cycle of the steam in the two engines must be limited to the qualities at cut-off in the high-pressure cylinders; but the varying conditions of the tests made on the 7-to-1 compound give data from which a definite idea as to its nature during the remainder of the stroke can be obtained.

VARIATION OF QUALITY OF STEAM.

No. of Case.	1	2	3	4
I. H. P. triple	45.56	62.99	112	126
I. H. P. 7-to-1 compound	38.87	66.85	98.09	129.97
Quality at cut-off in triple engine	32.8	46.4	67.2	70.8
Quality at cut-off, 7-to-1 compound engine	72.45	68.45	72.8	81.5
Water used by jacket of H. P. cyl. in triple engine	67.0	65.7	64.7	64.4
Water used by jacket of H.P. cyl. in 7-to-1 compound	59.5	62.5	67.8	63.0

The above table takes the four loads of the most economical low-pressure cut-offs, of the tests on the 7-to-1 compound, and compares the quality at the beginning of expansion with the quality of four as similar loads as could be obtained from the tests on the triple-expansion engine. As the jacket water is liable to affect the quality to some extent, the amount of jacket water used by the high-pressure cylinder during each of these tests is given. In considering these results, there is a difference in the range of pressure in the two cases of between 15 and 30 pounds, according to the loads, which, were there no effect due to the liberated heat caused by the drop, would mean an increase in the range of temperature, in the high-pressure cylinder of the 7-to-1 compound, of nearly double that in the same cylinder of the triple-expansion engine. In every case except the third, the jacket water used by the triple is in excess of the jacket water used by the compound; and yet, in spite of the difference in pressure range and the additional heat imparted by the jacket water, the quality at the beginning of expansion in the compound excels the quality at the same point in the triple by 30 per cent. for light loads and about 10 per cent. for heavy loads.

If further evidence of the effect of the drop in pressure between the cylinders is needed, it is given in the following tables, which show the variation in the quality of the steam, at the point of cut-off in both the high and low pressure cylinders, with the drop, in the 7-to-1 compound, grouped according to the steam consumed per hour.

EFFECT OF DROP ON QUALITY OF STEAM.

7-to-1 *Compound.*

Letter of Test.	Drop. 1.	Quality at Cut-off in Low Press. Cyl. 2.	Steam used by the Engine. 3.	Lbs. of Jacket Water per lb. of Steam. 4.	Quality at Cut-off in High Press. Cyl. 5.	Range of Temp. in High Press. Cyl. 6.
A..........	2.67	92.4	623.6	.31	68.4	114
E..........	4.27	103.8	600.5	.32	72.8	155
I..........	5.32	117.7	599.5	.28	72.4	122
M..........	6.75	115.1	648.2	.28	64.6	170
B..........	5.42	91.3	948	.24	64.6	125
F..........	8.53	94.6	938	.23	56.4	135
J..........	9.76	103.0	962.7	.23	58.1	146
N..........	12.62	114.3	927.0	.24	69.0	152
C..........	11.74	69.2	1,343	.22	76.0	110
G..........	12.95	66.9	1,280.8	.20	63.1	122
K..........	19.62	93.8	1,329.5	.20	72.8	138
P..........	16.1	91.6	1,557	.15	76.2	136
D..........	19.42	62.0	1,783	.172	82.2	99
H..........	30.79	80.5	1,720	.18	78.5	135
L..........	27.46	82.7	1,753	.18	81.5	121
Q..........	30.2	114.3	1,695	.172	70.2	134

NOTE.—Where, in the above table, a figure is given in excess of 100, it is an *apparent* quality, as shown by the indicator diagram. See Professor Carpenter's paper on "The Saturation Curve," *Trans.*, A. S. M. E., vol. xv., p. 904, for exact method.

Thus, *A*, *E*, *I*, and *M* are the lightest loads of the first, second, third, and fourth cut-offs, respectively; *M* to *N* the four next lightest loads; and *P* to *O* the four heaviest loads.

Column 1 gives the drop in pressure in the receiver, in pounds per square inch.

Column 2 gives the per cent. quality at cut-off in the low-pressure cylinder.

Column 3 gives the steam passing through the cylinders.

Column 4 gives the pounds of jacket water used by the engine per pound of steam passing through the cylinders.

Column 5 gives the quality of steam at cut-off in the high-pressure cylinder.

Column 6 gives the range of temperature in the high-pressure cylinders, as calculated from the steam-chest pressure and back pressure in that cylinder.

The effect of the drop on the quality at the beginning of expansion is as marked here as in the previous table. The irregularity of results prevents a close comparison; but there is

certainly no sensible decrease in quality due to increased range of pressure caused by drop.

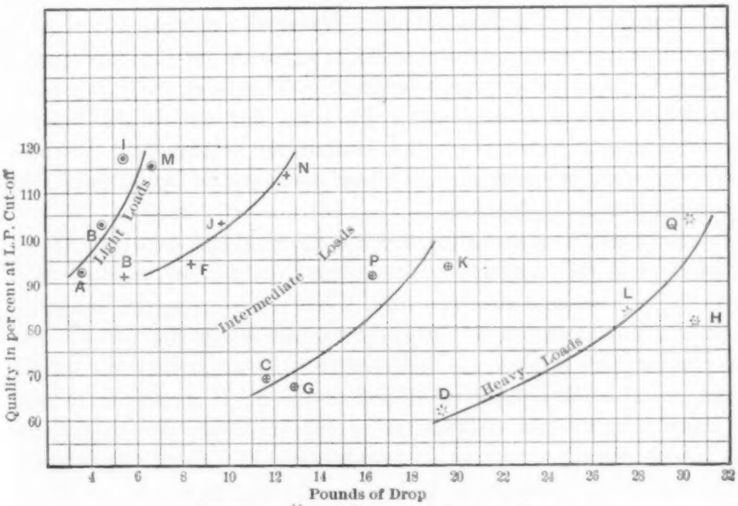
The effect of the drop on the quality at low-pressure cut-off shows even more marked results. When steam is acting in an engine under uniform conditions of boiler pressure and vacuum, there are four conditions which could affect the quality of the steam at cut-off in the low-pressure cylinder. These are the amount of compression, the quantity of steam passing through the engine, the weight of jacket water used per pound of working steam, and the point of cut-off in the low-pressure cylinder, which varies the drop and the distribution of the range of temperature between the cylinders. As the amount of compression was practically the same in both engines, it will not enter into the result. We also neglect the temperature range, which would complicate matters without affecting results materially. In each set of values the steam used by the engine and the proportion of jacket water are nearly constant. We can therefore find, by comparison, what is the effect of variation in drop on quality at low-pressure cut-off.

The curves in Fig. 47 show the variation of these quantities, the drop being the ordinate, and the quality of the steam in per cent. the abscissa. The curve nearest the origin is drawn for the lightest load; the loads of the curves increasing towards the left. The variation of the points from the curves corresponds to a certain extent to the variation of the jacket water per pound of steam condensed from the mean value for that curve. Another set of curves might also be drawn through points of the same cut-off, which would show the effect of the jacket water supplied per pound of condensed steam in varying the quality. In every case plotted there is an unmistakable increase in quality due to increase in drop, which is, to a certain extent, proportional to this increase. Thus in the curve for light loads an increase of two and a half pounds in drop gives an increase in quality of 15 per cent.; while for the heavy loads, with a drop increased by eight pounds, the corresponding increase in quality amounts to about 50 per cent.

As in both the triple and the 7-to-1 compound we have steam at the same pressures admitted to the high-pressure cylinder, undergoing the same number of expansions, and exhausted from the low-pressure cylinder under the same conditions, a comparison of these two engines is simply a comparison of the efficiency

of a cycle in which a continuous expansion line is maintained, and the internal waste reduced by the subdivision of the range of temperature with that of a cycle in which it is sought to reduce internal loss by sacrificing continuous expansion, with the hope of making up for the loss sustained by gains in other directions.

The account on the debit and credit side of the system can be summed up as follows: Although with drop there is a marked increase in the range of temperature when calculated from the



Thurston

EFFECT OF "DROP" ON QUALITY OF STEAM, IN LOW-PRESSURE CYLINDER AT CUT-OFF; CONSTANT LOAD.

FIG. 47.

increased range of pressure in the high-pressure cylinder, the liberated heat from the expanded steam in the high-pressure exhaust is sufficient to make up for this increased pressure range, and to give even a slightly improved quality at the high-pressure point of cut-off as a result of the drying off of cylinder walls, later referred to. This liberated heat also has the effect of superheating the steam, and thus of lessening internal loss in the low-pressure cylinder. There is also a gain of work, owing to the absence of an intermediate cylinder whose clearance volume exceeds that of the high-pressure cylinder.

To balance these useful effects of drop we have only the gain

by expansion in the intermediate cylinder; but, as demonstrated by these experiments, this gain is sufficient to outweigh all else, and to turn the balance in favor of a continous expansion line.

When the practical uses of the 7-to-1 compound are considered, although at a disadvantage when working at a constant load, under loads subject to large variation, such as exists in an electric-power plant, the flatness of the economy curve would seem to indicate that it would more than hold its own. In a comparison of the 7-to-1 with the 3-to-1 compound, all efficiencies seem to favor the larger cylinder ratio. Whether 7-to-1 is the most economical ratio, or whether the most economical cylinder proportion lies at some intermediate point, is beyond the scope of this series of tests to determine. The best cylinder ratio probably varies somewhat with the work for which the engine is intended, and in an exact determination of the best proportions for maximum economy there remains a large field for experimental investigation.

In studying the preceding figures, it must be carefully kept in mind that the real comparison is by *delivered*, rather than *indicated* power, and that the final basis of comparison must, in all cases, be the financial one. It is further to be noted that the curves here given as efficiency curves cover a much larger range of expansion than is either usual or economical in the ordinary commercial conditions of the market; the important and interesting data are those appurtenant to the lower values of the ratio of expansion in this series of engine trials.

The superior quality of steam in the high-pressure cylinder of the 7-to-1 compound engine, due, as it would seem, to the peculiar conditions affecting that machine, would indicate that the process of change of quality was the following: The exceptional drop at exhaust causes a correspondingly exceptionally complete discharge of the charge of mixed water and steam, unusually complete drying of the cylinder walls by reëvaporation, and such promptness of action that comparatively little heat is rejected from the dry cylinder wall during the exhaust period. This results in corresponding reduction of the heat-exchange waste during the succeeding induction period, and this, in turn, means some economy of heat, steam, and fuel, notwithstanding the fact of an exaggerated range of temperature and of pressure in the high-pressure cylinder, circumstances tending to increase wastes.

The main deduction, from a scientific point of view, if not from that of ordinary practice, being that the accepted system of multiple-cylinder engines with continuous expansion and with the number of cylinders in series determined by the steam pressure, the resultant desirable ratio of expansion and the quantity of consequent "cylinder condensation" is that which affords highest economical results, and that which constitutes the highest type of engine of our time, it becomes, further, desirable to ascertain what is the best adjustment of this particular series engine. This is now well understood to vary with the whole series of variable conditions affecting the engine—with size, with engine speed, with steam pressure, vacuum, and the condition of the working fluid and of the cylinder wall.

Taking the engine here illustrated, the three-cylinder series engine, as the most economical type of machine, and assuming its conditions of operation and its regular economies and wastes to be fairly representative of the average good machine of its class, we may easily ascertain where is its best adjustment, and how that critical point is affected by variation in the magnitude of its wastes.

The accompanying figure (Fig. 48) is a diagram in which are given the curves of efficiency of the real engine, of the ideal case, and of the hypothetical machine, subject to the various known wastes. The abscissas are measures of the ratio of expansion, and the ordinates give the weight of feed-water required to be supplied and to be evaporated into dry steam at boiler pressure per horse-power, indicated, per hour. The curve for the ideal case is easily and exactly obtained by now familiar processes of thermodynamics; those for the added wastes are also obtained as easily, and with fair approximation, by the use of empirical formulas based upon ample experiment. Thus we have the lower curve as that relating efficiency to the degree of expansion of the steam and identifying the simultaneous values of work and costs. It indicates gain by expansion until the expansion line intersects the back-pressure line on the indicator diagram. The next curve takes into account the wastes due to the fact that the actual engine is subject, in this case, to considerable clearance waste, and it is at once discovered that the efficiency passes through a maximum value with a ratio of expansion greatly restricted; in this case to about 33. In the next higher curve, the ordinates include the expenditures of the ideal, purely

thermodynamic case, the wastes due clearances and the thermal wastes by external conduction and radiation. It is seen that the introduction of these new forms of waste produce still further restriction of the economical ratio of expansion, and gain ceases when the ratio exceeds 30. Finally, adding the wastes due to internal condensation and leakage, as ascertained by trial of the engine, we have the upper curve, whose ordinates include all known expenditures. The ratio of expansion is now restricted to a minimum, and expenditures of heat, steam, and

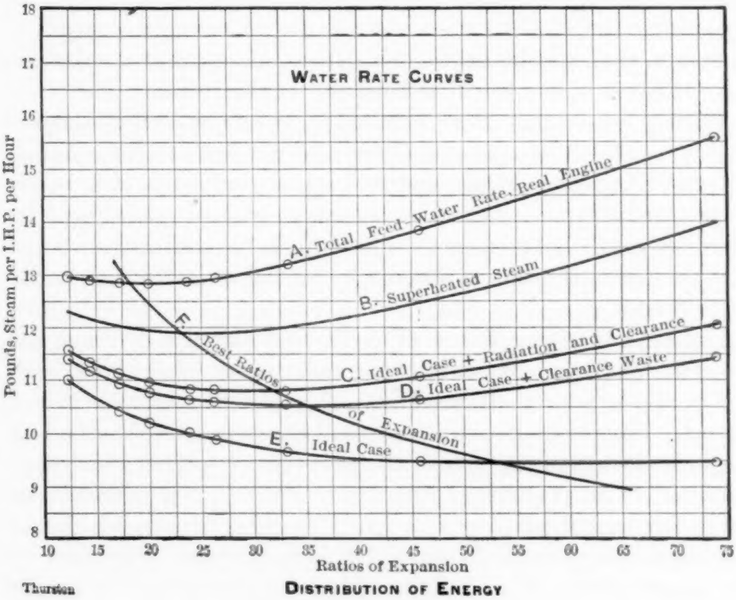


FIG. 48.

fuel begin to increase immediately upon passing this critical point, a ratio of 17. Were we to consider expenditures of capital incurred in the construction and installation, and in the maintenance of the plant, we should discover still further restriction, and probably would ascertain that a ratio of 10 or 12, at most, and in a compound engine, would prove, financially, the best form that the investment could be made to take in planning the plant.

Referring to the diagram once more, it will be observed that a fifth curve, *F*, is drawn diagonally across, from the upper

and smaller critical point, through the intermediate values of the best ratios of expansion, each for the set of conditions assumed; and thus the locus is obtained for the curve of successive values of the ratio of expansion of best thermal effect for varying quantities of waste. Its equation for this particular engine is, $y = \frac{17}{\log x}$; is that of a curve, simple in form, and very easily located, as seen, on which may be found the measures of costs of power with any stated quantities of extra thermodynamic waste. For example, when it becomes practicable to reduce the internal wastes of the engine, curve A, to one-half their present amount, as by sufficiently superheating the entering steam, the curve B in the diagram, next below the uppermost, for the real engine, will be produced, and the ratio of expansion giving highest duty will be found at once to be increased by this improvement from 17 to 23; and the consumption of steam measured in the saturated condition, or its equivalent, will fall from 12.8 to less than 12 pounds. Similarly, a steam cylinder composed of, or lined with, a non-conducting material, as often proposed by Emery and others, would reduce the cost to less than 11 pounds, and the extinction of clearance would still further reduce it to about 10 pounds; while the ratios of expansion for such best effects would rise, respectively, to 30 and to about 40.

A more correct comparison with the best work of the compound engine may be made by employing the accompanying diagram, Fig. 49, in place of the data from the small compound here used in experiment, and making the comparison with the best records of triple engines and of the special type of compound, the examination of which constitutes a principal feature of this paper. This engine is designed for 150 pounds steam pressure with complete expansion, and its proportions are those of the standard and ideally correct type of compound engine. The machine is of 1,850 indicated horse-power, cylinders 32″ + 68″ × 60″, making 74 revolutions per minute, and giving the horse-power on 1.35 pounds of coal and about 12.5 pounds of steam, and 13,000 British thermal units per hour.* Taking this engine

* The treasurer of the cotton-mill in which the orthodox form of compound above described is at work certifies to the writer the following figures for costs of power. It will be interesting, as time goes on, to compare these data with similar statements for other types of engine; since it is this financial test which,

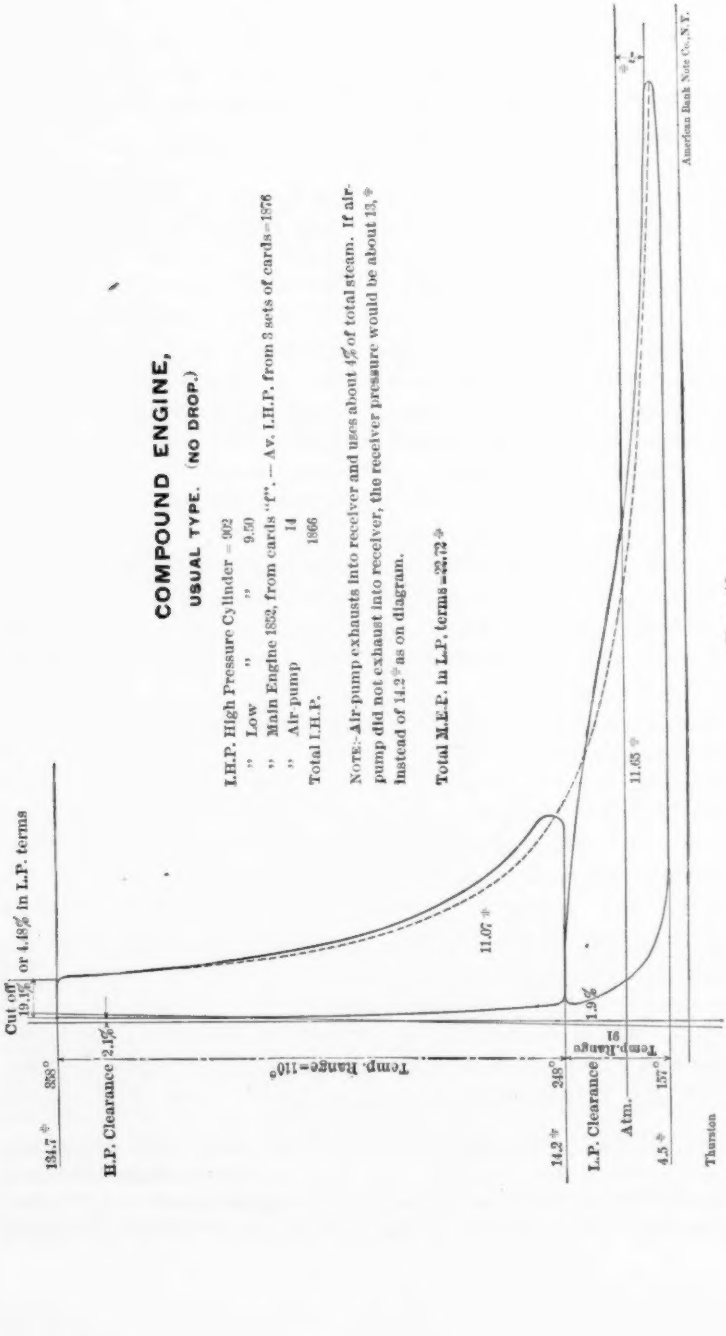

COMPOUND ENGINE,
USUAL TYPE. (NO DROP.)
I.H.P. High Pressure Cylinder = 902
" Low " " 950
" Main Engine 1852, from cards "f". — Av. I.H.P. from 3 sets of cards = 1878
" Air-pump 14
Total I.H.P. 1866
NOTE:- Air-pump exhausts into receiver and uses about 4% of total steam. If air-pump did not exhaust into receiver, the receiver pressure would be about 13.# instead of 14.2# as on diagram.
Total M.E.P. in L.P. terms = 22.72#
Cut off 19.1% or 4.18% in L.P. terms
134.7#
358°
H.P. Clearance
2.1%
Temp. Range = 110°
11.07#
1.9%
14.2#
248°
L.P. Clearance
Atm.
11.65#
Temp. Range 91
4.5#
157°
Thurston
American Bank Note Co., N.Y.

FIG. 49.

as standard for its type, the Milwaukee pumping engine for the triple expansion, and the best example of the special form of compound, for comparison, we have for the three the following expressions for their relative efficiencies as measured in steam consumption, in pounds per indicated horse-power per hour, and heat supply:

For the triple-expansion engine, $W = \dfrac{24}{\log p}$; $H = \dfrac{28,800}{\log p}$; . (1)

For the standard compound, $W = \dfrac{27}{\log p}$; $H = \dfrac{32,800}{\log p}$; . (2)

For the special form of compound, $W = \dfrac{29}{\log p}$; $H = \dfrac{34,800}{\log p}$; . (3)

The latter is seen, on examination of its proportions, to be a form of engine designed for an abnormally high total ratio of expansion at the proposed pressure, and assigned an abnormally heavy load, so that when actually in action under its average load, it must work with a low ratio of expansion in the high-pressure cylinder, and must exhibit an abnormally large "drop" at its exhaust. It is a compound engine thermodynamically misapplied, and operated under conditions—ideally, at least—

after all, settles all questions of exact adaptation of type of engine and of correct proportions and construction. Coal costs here $2.26 per ton.

Fuel per horse-power per year of 3,070 hours	$4 70
Labor	1 88
Supplies and repairs	42
Total for operating expenses	$7 00
Interest at 5 per cent	$2 05
Depreciation at 5 per cent	2 05
Taxes	41
Insurance	04
Fixed charges	$4 55

"According to the Providence (R. I.) *Journal*: 'This is lower than anything yet found. It is due to the large size of plant, which reduces the labor and supply account per horse-power, and to low cost of fuel and insurance and low cost of plant on account of its size. The cost of plant includes a Green economizer-chimney boiler house, engine house and foundations—all first-class—water-tube boilers, whose depreciation ought not to be 2½ per cent. If steam used for no other purposes than power were deducted, it would reduce the fuel 10 per cent., or 47 cents per year, per horse-power, making the total $11.08. There is no way of separating this amount from the total in the regular accounts.'

"So far as known, this is the lowest cost of steam power in any New England textile mill. The tons of fuel per horse-power per year are reported as 2.08—the lowest noted; some others run about 2.20 tons per horse-power and up."

R. H. T. in *Science*.

defective. It remains to be seen, however, whether with variable load this may not prove on the whole a practically correct and financially efficient system.

APPENDIX A.

Abridged Log of Engine Trials.

COMPOUND ENGINE—CYLINDER RATIO, 7 TO 1.

Letter of Test.	Revolutions per Minute.	Temperature.					Boiler Press. Gauge.	Barometer. Inches.	Condenser. Inches. H. G.
		Condensing Water.		Condensed Steam.	Engine Room.	External Air.			
		Cold.	Warm.						
A.......	88.83	44.1	67.8	82.7	86.4	51	117.5	29.4	24.26
B.......	87.65	37.1	74.3	94 8	89.5	44.1	119.6	29.236	24.16
C.......	86.52	36.4	74.9	99.2	85.9	42.9	117.9	28.860	23.4
D.......	85.42	36	77	106.2	90.7	51	117	28.080	23.07
E.......	88.96	45.1	71.9	86.2	88.6	54.2	119.5	29.35	24.04
F......	87.73	40.7	67.8	89.2	84.2	40.5	114.8	28.65	25.05
G.	86.71	36	68.4	96.7	86.8	23.5	110.3	29.412	24.7
H.......	85.51	35.7	69.4	102.1	96	41.5	119	29.044	23.57
I........	88.92	40.8	60.2	78	92.7	58.6	119.5	29.026	23.77
J	87.79	36.2	74.9	96.6	93.9	44.5	119.8	29.152	23.58
K.......	86.72	36	73.8	100.8	93.5	46.2	118.4	29.118	23,68
L.......	85.7	48	91.3	116	95.2	52.6	118.9	29.25	22.84
M.......	88.95	39.3	60.7	80	95.6	58.5	118.5	29.000	23.7
N.......	87.61	35	67.1	93.9	87.5	39.7	119.1	29.190	23.28
O.......	86.71	36.5	70.5	101.9	90.1	21.2	114.3	29.412	24.04
P	85.93	42	74.5	102.1	89.2	35.5	112.3	28.3	24.85
Q	85.61	34.2	69.5	102	93	42	118	29.19	24.13

Letter of Test.	Condensing Water Total per Hour Lbs.	Steam per Hr. Lbs. I. H. P. Corrected Calorimeter.	B. T. U. per I. H. P. per Minute.	Real Ratio of Expansion.
A............	32,900	20.1	401	67.8
B............	25,400	17.45	384.4	52.5
C............	36,100	16.38	327	27.87
D...	40,600	16.78	335.5	19.06
E............	28,500	19.25	385	67.8
F............	35,000	16.64	331	......
G............	36,700	16.88	336	33.7
H............	33,100	15.9	319	21.12
I............	32,800	19.7	398	67.8
J............	25,500	17.75	354	54.75
K............	33,800	16.28	324	30.3
L............	37,200	15.8	316	19.89
M............	31,200	21.0	414	67.8
N............	29,200	18.2	364.2	52.0
O............	33,700	16.6	331.4	32.42
P............	46,800	16.27	324	23.15
Q............	49,000	15.88	318	21.36

Letter of Test.	Indicated Horse-Power.				Total I. H. P.	Total D. H. P.
	High Pressure.		Low Pressure.			
	Head.	Crank.	Head.	Crank.		
A	10.32	11.87	9.35	8.81	40.35	28.65
B	18.49	17.31	15.2	15.63	66.63	57.6
C	25.93	24.88	24.2	22.9	97.91	84.75
D	32.22	28.12	31.3	31.6	123.24	111.5
E	10.93	11.76	9.45	8.79	40.73	28.82
F	19.52	16.9	17.03	15.58	69.03	56.21
G	23.15	21.20	18.4	21.9	84.65	74.35
H	33.98	30.57	32.4	29.02	126	111.6
I	11.68	12.39	7.55	7.25	38.87	28.74
J	20.77	19.53	13.5	13.05	66.88	57.09
K	30.32	26.48	21.3	19.99	98.09	85.7
L	34.04	33.33	30.2	28.4	129.97	111.79
M	11.81	12.83	7.85	6.95	39.44	28.97
N	20.66	20.15	11.85	10.30	62.90	54.56
O	28.39	24.42	18.2	16.63	86.64	76.85
P	34.45	29.45	23.93	21.83	109.66	95.32
Q	39.02	32.81	27.3	24.9	124	113.08

Letter of Test.	Jacket Water.			Quality of Steam.			
	High Pressure.	1st Receiver.	2d Receiver.	Cut-off.		Release.	
				High Pressure.	Low Pressure.	High Pressure.	Low Pressure.
A	65.3	72	56.4	68.4	92.4	83.9	130.5
B	64.7	90.4	67.1	65.7	91.3	91.7	125
C	67.5	128	78	76	69.2	85.4	96.75
D	63.8	156	87.5	82.2	62	85.5	86.2
E	64.4	69	60.7	72.8	103.8	88.2	139
F	64	93.6	60.4	56.4	94.6	79.1	115
G	58.7	125.3	71.8	63.1	66.9	80.8	98.1
H	60.2	158.5	86.5	78.5	80.5	85.1	94.3
I	59.5	62.1	50.2	72.45	117.7	88.7	143
J	62.5	103	68.8	58.1	103	79.6	113
K	67.8	113.5	75.2	72.8	93.8	86	103
L	63	115.5	98.2	81.5	82.7	87.2	100
M	61	65	59.8	64.6	115.1	79.9	113
N	61.6	98.9	68.4	70.3	114.3	94.6	133
O	61.3	120.5	70.3	69	107.7	84.9	115
P	60.2	102.2	74.5	76.2	91.6	83.7	92.2
Q	60	139.5	93	70.2	114.3	87.2	132.5

APPENDIX B.

The Logs of the Trials Follow in Abstract.

TRIPLE-EXPANSION ENGINE.

Symbol.	Revolutions per Minute.	Gauge Readings. Pounds. Boiler.	Pounds. Steam Pipe.	Pounds. 1st Receiver.	Inches—Height. 2d Receiver.	Inches—Height. Condenser.	Inches—Height. Barometer.	Temperature External Air.
F_1........	83.77	119.3	116.3	37.7	2.3	24.2	29.318	78
F_2........	84.95	119.1	116.1	25.3	1.7	24.3	29.318	84
F_3........	85.45	117.1	114.1	20.1	2.9	23.3	29.318	85
F_4........	86.17	118.4	115.4	10.8	5.6	24.1	29.324	86
F_5........	87	117.9	114.7	5.3	6.3	22.9	29.324	89
F_6........	87.48	118	115	3.1	7	22.1	29.324	91
F_7........	87.97	117.1	114.1	8.6	7.5	21.6	29.234	90
F_8........	84.41	117.2	114.2	23.5	.9	24.1	29.301	67.2
	Compound Engine.	Cylinder Ratio 3 to 1.						
D_1........	84.4	109.9	106.9	14.5	....	22.6	29.354	48
D_2........	85.48	108.9	106.3	8.1	....	22.7	29.254	49
D_3........	86	115.4	112.7	2.4	....	21.5	29.246	68
D_4........	87.15	114.9	112.1	1.1	....	21.8	29.346	69
D_5........	87.72	116	114.3	4.5	....	23.8	29.325	76
D_6........	87.83	115.4	112.4	5.5	....	23.5	29.325	78
D_7........	87.97	116.4	113.4	6.7	....	23.3	29.325	78
D_8........	85.52	117.5	114.5	4,7	....	22.7	29.35	75

TRIPLE-EXPANSION ENGINE.

Symbol.	Temperatures. Eng. Rm.	Temperatures. Condensed Steam.	Temperatures. Water. Inj.	Temperatures. Water. Disch.	Cal. Steam Pipe.	Weights Condensed Steam.	Cu. ft. Inj. Water.	Total Brake Load.
F_1.....	95.6	113.4	54	88.1	287.6	1,809	835	1,186
F_2.....	98.6	106.1	55	82.4	287.3	1,205	704	916
F_3.....	100	104.9	56.6	83.6	286.4	1,010	601	686
F_4.....	99	97.7	57	78	240.3	767	635	436
F_5.....	103.4	99	59.3	85.3	290.6	554	332	286
F_6.....	105	100.9	60.9	87	290.9	472	305	186
F_7.....	104.9	107.6	62.1	104	290	399	209	81
F_8.....	94.6	106.6	59	84.6	287.8	1,438	891	1,036
	Compound Engine.	Cylinder Ratio 3 to 1.						
D_1.....	70.9	116.4	44	83.7	291.4	1,639	619	886
D_2.....	70.9	103.9	44.6	73.3	291.3	1,214	605	686
D_3.....	78	102.1	54	83.1	283.9	915	459	486
D_4.....	77.1	88.9	53	75.7	284	575	364	280
D_5.....	89.3	76.9	50.6	63	283.6	368	443	186
D_6.....	86.7	81.4	51.7	79.3	281.7	336	204	136
D_7.....	90.3	82.3	53.3	86	282.6	287	140	87
D_8....	92	107.1	54.4	83.2	282.3	1,030	542	586

TRIPLE-EXPANSION ENGINE.

Symbol.	Jacket Steam Per Hour. Lbs.					Total Steam per Hour, including Jackets.	Total Quality of Steam Beginning of Expansion.
	High Pressure.	Int.	1st Receiver.	2d Receiver.	Total. Jacket Steam.		
F_1	63.85	133.5	120	46.33	363.7	2173.9	70.8
F_2	64.7	99.8	123.6	47.3	335.4	1540.6	67.2
F_3	62.3	89.3	116.8	58.4	326.8	1337.0	55.2
F_4	65.7	82.0	90.8	59.9	298.4	1065.4	46.4
F_5	67.0	76.6	60.1	48.3	252.0	806.5	32.8
F_6	62.9	69.4	65.4	44.0	241.3	714.2	28.3
F_7	65.8	73.9	52.3	40.1	252.1	631.7	28.7
F_8	64.4	117.8	115.7	55.4	353.3	1791.9	70.8
	Compound Engine. Cylinder Ratio 3 to 1.						
D_1	67.57	....	136.08	....	203.65	1843.1	72.7
D_2	62.28	....	141.37	....	203.55	1418.1	69.5
D_3	59.32	....	94.43	....	153.75	1069.5	60.9
D_4	62.71	....	74.58	....	137.29	712.3	48.6
D_5	70.33	....	60.03	....	130.36	498.4	42.6
D_6	71.3	....	60.03	....	131.33	447.4	109
D_7	70.82	....	54.75	....	125.47	412.5	108
D_8	61.59	....	129.38	....	190.97	1221.2	108

TRIPLE-EXPANSION ENGINE.

Symbol.	I. H. P. Cylinder.				Total D. H. P.	Mech. Eff.	Pounds Steam per I. H. P. per Hour.	No. of Expansion.
	H. P. C.	Int. C.	L. P. C.	Total.				
F_1	39.27	46.57	55.89	141.4	122.9	86.90	15.37	
F_2	37.98	37.26	37.39	112.65	94.8	84.1	13.68	
F_3	32.79	29.48	27.51	89.79	72.5	80.79	14.89	
F_4	24.20	21.80	17.02	62.99	45.5	72.2	16.82	
F_5	19.11	15.29	11.16	45.56	30.9	67.59	17.70	
F_6	14.42	12.68	6.81	33.93	19.3	57.0	21.05	
F_7	12.26	9.96	3.99	26.21	33.65	24.10	....	
F_8	37.98	41.51	47.0	127.54	108.23	85.53	14.16	
	Compound Engine. Cylinder Ratio 3 to 1.							
D_1	54.20	45.54	....	99.75	93.0	92.9	18.48	7.66
D_2	44.22	33.21	....	77.44	21.0	92.0	18.18	11.4
D_3	36.04	20.53	....	58.24	51.7	89.2	18.36	17.19
D_4	22.88	12.64	....	35.57	29.3	82.5	20.02	32.04
D_5	14.18	9.04	....	25.22	20.02	80.0	21.46	41.44
D_6	12.88	7.13	....	20.01	14.8	73.9	22.36	43.06
D_7	10.93	5.29	....	16.22	10.0	61.7	26.01	46.40
D_8	41.44	26.22	....	67.74	61.02	90.0	18.03	15.45

SUPPLEMENT.

THURSTON ON MULTIPLE-CYLINDER ENGINES.

Since the preceding paper was printed, there has appeared the report of a series of trials of another engine having the peculiar proportion of high to low pressure cylinders here under discussion. These tests were made by Mr. Barrus at the Grosvenor Dale Mills, and the conditions and results of the tests are such as throw some light upon the question at issue. The dimensions and the data obtained are presented in the accompanying tables.*

The weight of feed-water, as deduced from the second of the three trials, was $\frac{W = 2.62}{\log. p} = 12.03$, at 150 pounds steam pressure. Reduced to 175 pounds, the figure becomes 11.7; which is much better than the earlier figure for the same pressure (12.84), but still inferior to that of the best triple-expansion engines, and is practically identical with the best record for the large compounds. The first trial gave a result of two per cent. above this figure; the last gave one per cent. better.

Noting the conditions which distinguish the several trials, it will be observed that the engine does better work as its steam distribution gives a closer approximation to the ideal form of engine diagram, as the drop becomes less pronounced, and its wastes are thus reduced. The first trial was made with the cut-off at 0.285 in the high and 0.323 in the low pressure cylinder; the second with cut-offs, respectively, at 0.287 and 0.236; the third trial with cut-offs at, respectively, 0.285 and 0.176; thus gradually backing up the receiver pressures in such manner as to make the combined card more and more similar to the ideal, and its expansion line more and more nearly continuous, and thus raising the initial pressure in the low-pressure cylinder from 15 to 21 pounds, while the terminal pressure, in the high, remains at about 43. Thus the evidence, to date, would seem to indicate that, as a matter of engine efficiency, the complete equalization of expansions between the cylinders, and the adoption of an expansion without drop between the cylinders, would give still better results, and that these better results might be

* *Engineering Record*, November 20, 1897, p. 541.

expected to closely accord with those obtained under the most favorable conditions by engines proportioned and operated as customary by the majority of most successful constructions.

The following is Mr. Barrus's report, changed in form slightly for convenience in printing.*

"The engine company guaranteed" a duty of $12\frac{1}{2}$ pounds of dry steam per horse-power per hour with steam at 150 pounds boiler pressure, and at not less than 140 pounds pressure at throttle valve; steam to be commercially dry and contain not over two per cent. moisture. Vacuum in condenser to be not less than 26 inches, and the load on engine to be within its economical range.

The guarantee tests were simple feed-water trials, and these were divided into three periods of exactly five hours each. Data upon the work of the boilers were also obtained, so as to make the tests a full trial of the complete plant. This trial was commenced at noon, September 8th, and ended at the same time September 10th, after a working run of 48 hours. During this time the engine was run each day from 6.40 A.M. to 12 M., and from 12.40 P.M. to 6 P.M. At night the fires were left in the usual manner, and no steam was drawn from the tube boilers concerned in the test, except that required for the jackets of the engine, which it is the practice to keep constantly heated.

DESCRIPTION OF PLANT.

The steam plant here, which is all new, consists of four Manning vertical boilers of the 67-inch size, made by the Stewart Boiler Works, Worcester, Mass.; a Green economizer having 192 pipes, furnished by the Fuel Economizer Company, of Matteawan, N. Y.; a brick chimney 5 feet inside diameter, 150 feet high, and the engine under consideration, which is a cross-compound jacketed machine with syphon condenser.

The piping of the boilers is so arranged that any one or more boilers can be used independently for the supply of the engine, and the remaining boilers devoted to the miscellaneous heating work, etc., of the mill. While the test was going on the two boilers were used for the engine, and the single one nearest the chimney for the other work. The remaining boiler was idle, and in this the damper and fire doors were kept closed. The feed-

* *Engineering Record*, November 20, 1897.

water for the two engine boilers, which was supplied by a belted pump, alone passed through the economizer, that for the third boiler being supplied independently. The gases escaping from all three boilers passed through the economizer, and the engine plant had the benefit of this. The conditions of running the economizer were thus slightly different from those of customary practice.*

The length of steam pipe, which is 9 inches diameter from the boiler-room to the throttle valve, is 75 feet, and its surface together with the flanges is well covered with magnesia. The pipe contains a Webster separator 5 feet from the throttle valve. The draft is controlled by a Locke damper regulator, which acts upon a damper between the economizer and the chimney.

The high-pressure cylinder is jacketed all over. The heads of the low-pressure cylinder are jacketed, but the barrel is unjacketed. The reheater contains 187 square feet of surface. The jacketed spaces are filled with steam of full pressure and drained by a trap, or automatic pump and receiver, at will. The latter is ordinarily used and the hot jacket water returned to the boilers. During the test the trap served this purpose and discharged into the weighing tub of the feed-water measuring apparatus, thence passing on to the boilers. The intermediate receiver is drained by a trap which discharges to waste. The essential dimensions of the boilers, economizer, engine, and piping are given in Table No. 1, as follows:

TABLE NO. 1.

Boilers.

Diameter of shell, in.	67
" " water leg, outside, in.	85
" " firebox, in.	78
(Air and metal spaces in grates ½ in. and ½ in.)	
Height of firebox, in.	51
Length of tubes, ft.	15
Number of tubes, 2½ in. outside diameter	228
Flue opening, approximate, in.	18 x 48
Length of tube surface above average water line, in.	57
Area grate surface (each), sq. foot	33.2
" of water heating surface (each), sq. ft.	1,489
" " steam " " " " "	665

* The specifications accompanying the contract fix the most economical load at 650 horse-power.

Area of total heating surface (each), sq. ft.	2,154
" through tubes, sq. ft.	6.3
Ratio of water heating surface to grate	44.8 to 1
" " steam " " "	20 " 1
" " grate to tube area	5.3 " 1
Area grate surface, 2 boilers, sq. ft.	64.4
" water heating surface, 2 boilers, sq. ft.	2,978

Economizer.

No. of tubes	1.92
Area of heating surface (approx.) sq. ft.	2,304

Flues and Chimney.

Size of main flue, ft.	3x7.5
Area main flue, sq. ft.	22.5
Diameter chimney flue, ft.	5
Area " " sq. ft.	19.6
Height of chimney, ft	150

Engine. (Partly builder's measure.)

Diameter high pr. cylinder, in	18
" " " rod, in	$3\frac{5}{8}$
Stroke, H. P. cylinder, ft.	4
Steam port area, high pr., sq. in	28.4
Exhaust " " " " " "	38
Clearance " " per cent	2
H. P. constant 1 lb. m. e. p. 1 rev. per min., H. P. cyl., H. P	0604
H. P. constant 1 lb. m. e. p. 80 rev. per min., H. P. cyl., H. P.	4.83
Diameter low pr. cylinder, in	$48\frac{1}{4}$
" " " rod, in.	$4\frac{5}{8}$
Stroke, L. P. cyl., ft	4
Steam port area L. P., sq. in	163.5
Exhaust " " " " " "	208.3
Clearance, per cent	2.87
H. P. constant 1 lb. m. e. p. 1 rev. per min., L. P. cyl	4412
H. P. constant 1 lb. m. e. p. 80 rev. per min., L. P. H. P.	35.3

The valves and pistons were examined for leakage prior to beginning the feed-water tests, using the methods commonly practised by the writer. The engine was in fair condition throughout. There was some leakage of the high-pressure piston, though not serious, and the exhaust valve of the low-pressure cylinder crank end was found to leak a good deal. The engine, as a whole, was in much better condition in respect to leakage than the one at the North Grosvenor Dale mill, which the writer tested in 1895.—*Engineering Record*, Nov. 3, 1895.

The contract tests covered periods in the afternoon from 12.55 to 5.55 o'clock and in the forenoon from 6.55 to 11.55 o'clock. They were made with three different receiver pressures. The jacket water was weighed separately. The weight of water determined is corrected for the leakage of the boilers, which was found to be 96 pounds per hour.

During the progress of the tests a set of indicator diagrams was taken from each end of each cylinder at intervals of 30 minutes. At similar intervals the various pressure gauges, the speed and temperature of the steam near the throttle valve were observed. The gauges and the indicator springs were also verified. The steam and vacuum gauges in the engine-room are practically correct. The receiver gauge is about right at 5 pounds. It indicates 2 pounds less than the actual pressure at 9 and 13.

Beginning just before covering the fires at noontime, September 8th, and ending just before covering at noon, September 10th, the coal was weighed and all the usual observations taken which pertain to a boiler and economizer test. The water was measured during the night, including that discharged from the jackets, the same as during the running time. A reasonably successful attempt was made to separate the coal used during the day from that of the night periods, but a better idea of the consumption of coal under the conditions of the working load can be obtained from the coal burned during selected periods, beginning after the boilers were well at work and ending before they were checked for stopping time. For such periods, aggregating 14.27 hours, out of a total running time of 16 hours, September 9th and 10th, the consumption of coal amounted to 11,399 pounds or 798.8 pounds per hour (uncorrected for the 2.8 per cent. moisture). The total running time during the second day was 10.6 hours, and the consumption of coal at this rate during that time is $798.8 \times 10.6 = 8{,}467$. The actual consumption for all purposes for the 24 hours of the second day was 9,995 pounds. It appears then that $9{,}995 - 8{,}467$ equals 1,528 pounds was used in maintaining the steam during the night and noontime, or 15.3 per cent. The weight of water evaporated during the night and noon times on the second day's run was 4,635 pounds, or 5.4 per cent. of the total evaporation for the entire 24 hours, this total being 88,857 pounds. About 10 per cent. of the coal was therefore lost during the 13.4 hours while the engine was idle.

During the afternoon of September 8th the jacket water was weighed for only 50 minutes, the balance of the time being turned into the lower tank unweighed. During the evening of September 8th the jackets were shut off for some time, and some water was lost in trying to work the injector. It has been deemed best, therefore, to confine the coal measurements and boiler work to a single 24 hours' run—that of the second day.

The date and results of the general test of the plant and of the boiler test are given in Tables 4 to 6. Of these, Table No. 4 gives the results of general test computed from the 14.27 hour period referred to above; Table No. 5 the results for the full 24 hours' run of the second day; and Table No. 6 the data and evaporative results based on the 14.27 hour period.

The flue gases were analyzed from time to time. An average of four tests gave the following composition by volume:

Carbonic acid (CO_2)	13.1	per cent.
Oxygen (O_2)	5.7	" "
Carbonic oxide (CO)	0.6	" "
Nitrogen, etc. (by difference)	80.6	" "
	100.0	" "

The trap which drains the bottom of the receiver discharged on September 10th at the rate of 184 pounds per hour. The jacket water for the three engine trials averaged 9.5 per cent. of the total weight of steam supplied. This is included in the quantities of feed-water given in the tables of engine results.

TABLE No. 2.

DATA AND RESULTS OF FEED-WATER TESTS OF AMERICAN WHEELOCK ENGINE AT GROSVENOR DALE, CONN.

RECEIVER PRESSURE, LBS. (NOMINALLY).	Test No. 1. 5.	Test No. 2. 9.	Test No. 3. 13.
1. Duration, hours	5.0	5.0	5.00
2. Total weight of feed-water consumed, lbs	41,690.0	40,063.0	39,654.00
3. Weight of water consumed per hour, corrected for leakage of 96 lbs	8,242.0	7,916.6	7,834.8
4. Indicated H. P. developed, h. p.	670.5	658.1	659.1
5. Average pressure in steam pipe, lbs	149.7	150.4	150.2
6. Number of degrees superheating, deg	15.7	16.4	12.2
7. Receiver pressure by gauge, lbs	5.4	9.1	12.9
8. Vacuum in condenser, in	26.9	26.4	26.6
9. Number of revolutions per minute, rev	80.04	80.14	80.0
10. Mean effective pressure H. P. cyl., lbs	72.44	65.89	61.9
11. Mean effective pressure L. P. cyl., lbs	9.03	9.59	10.2
12. Feed water consumed per indic. horse-power per hour, lbs	12.29	12.03	11.89
13. Dry steam consumed per I. H. P. per hour, lbs.	12.40	12.14	11.97

TABLE NO. 3.

Measurements and Computations Based on one set of Sample Diagrams.

	Test No. 1.		Test No. 2.		Test No. 3.	
14. Pressure in steam pipe, lbs....	151.0		150.2		150.5	
15. Receiver pressure by gauge not corrected, lbs...............	5.5		9.0		12.8	
	H. P. Cyl.	L. P. Cyl.	H. P. Cyl.	L. P. Cyl.	H. P. Cyl.	L. P. Cyl.
16. Initial pressure above atmosphere, lbs..................	143.9	5.2	141.8	9.9	143.0	14.5
17. Cut-off pressure above zero, lbs.........	149.0	15.4	147.8	19.9	145.9	24.7
18. Release pressure above zero, lbs.................... ...	42.5	5.2	43.4	5.2	43.0	5.2
19. Compression pressure above zero, lbs....................	28.0	5.4	36.4	6.4	38.8	7.7
20. Mean effective pressure, lbs...	72.70	9.08	66.75	9.61	62.27	10.23
21. Back pressure at mid stroke above or below atmosphere, lbs.........................	+6.0	−13.1	+12.5	−12.8	+16.5	−13.0
22. Proportion of forward stroke completed at cut-off	.285	.323	.287	.236	.285	.176
23. Proportion of forward stroke completed at release	.981	.927	.975	.913	.979	.895
24. Proportion of backward stroke uncompleted at compression.	.065	.064	.062	.064	.072	.036
25. Steam accounted for at cut-off, lbs......................	9.54	9.07	9.54	8.57	9.21	7.96
26. Steam accounted for at release, lbs.........................	9.62	8.88	9.76	8.65	9.58	8.43
27. Proportion of feed-water accounted for at cut-off.......	.770	.732	.786	.706	.769	.664
28. Proportion of feed-water accounted for at release..... .	.776	.716	.800	.712	.800	.704

TABLE NO. 4.

Data and Results of Engine and Boiler Test for 14.27 Hour Period.

1. Duration, hrs.............. .... 14.27
2. Weight of dry coal consumed, lbs.................................. 11,080
3. Dry coal consumed per hour, lbs............. .... 776.5
4. Average indicated horse-power developed by engine, H. P 660.1
5. Coal per I. H. P. per hr. for period of 14.27 hrs., lbs................ 1.18

TABLE NO. 5.

Data and Results of Engine and Boiler Test for 24-Hour Working Run.

1. Duration, or length of time engine was running at speed, hrs 10.6
2. Weight of dry coal consumed, including banking coal, etc., lbs...... 9,715
3. Estimated percentage of total coal used during time when engine was idle, per cent......... 15
4. Total weight of water evaporated, lbs............................. 88,857
5. Estimated percentage of total water used during time when engine was idle, per cent 5
6. Dry coal consumed her hour, lbs....... .... 916.5
7. Average indicated horse-power developed by engine, H. P........... 658.6
8. Coal per I. H. P. per hour for entire 24 hrs., lbs.................... 1.39

TABLE NO. 6.

Data and Results of Evaporative Tests on Manning Boilers at Grosvenor Dale, Conn.

Kind of coal	Cumberland
Percentage of moisture in coal	2.8%
Date	September 9-10, 1897

Total Quantities.

1. Duration, hrs	14.27
2. Weight of dry coal consumed, lbs	11,080
3. Weight of ashes and clinkers, per cent	
4. Percentage of ashes and clinkers, per cent	8.5
5. Weight of water evaporated	

Hourly Quantities.

6. Coal consumed per hour, lbs	776.5
7. Coal per hour per sq. ft. of grate, lbs	11.7
8. Water evaporated per hr., lbs	8,094
9. Equiv. evaporation per hr. feed 100 deg., pressure 70 lbs., lbs	7,458
10. Horse-power developed, A. S. M. E. basis of 30 lbs., H. P.	248.6
11. Equiv. evaporation per sq. ft. heating surface per hour, lbs	2.5

Averages of Observations, etc.

12. Average boiler pressure, lbs	153.4
13. Aver. temp. feed-water, entering economizer, deg	101.3
14. Aver. temp. feed-water, leaving economizer, deg	209
15. Aver. temp. flue gases entering economizer, deg	520
16. Aver. temp. flue gases leaving economizer, deg	322
17. Average draft suction, in	16
18. Number degrees superheated, deg	12.40
19. Weather and outside temperature	Clear-Hot
20. Total heat of combustion per pound of dry coal, B. T. U	13,970
21. Total heat of combustion per pound of combustible, B. T. U	14,869

Results.

22. Water evaporated per pound of dry coal, lbs	10,424
23. Equivalent evaporation per pound of dry coal from and at 212 degrees, including superheat and including economizer, lbs	12,208
24. Equivalent evaporation per pound of combustible from and at 211 degrees, including superheat and including economizer, lbs	13,343
25. Efficiency on combustible, not including economizer, per cent	78.2
27. Efficiency on combustible, including economizer, per cent	86.5

Note.—The total weight of dry coal consumed for the 24-hour run of the second day, including banking coal, etc., was 9,715 pounds, and the total weight of water evaporated, 88,857 pounds. The water evaporated per pound of dry coal was 9,146 pounds, as against the 10,424 pounds given above for the 14.27-hour period.

DISCUSSION.

Mr. Frank H. Ball.—This paper is a valuable addition to the sum of knowledge regarding the steam engine, and the experimental investigation which it reports is of special interest in the study of multiple cylinder engines. It is to be regretted, however, that the authors did not give us some more clearly defined conclusions which, in their judgment, are derived from the data of their trials.

On page 154, the last sentence of the third paragraph makes the following announcement of the purpose of the investigation that is to follow: "The question is not whether a two-cylinder is better than a three-cylinder series engine, but whether novel proportions are to be adopted with the older type of engine." From this announcement we are led to expect some definite conclusions as to the relative merits of the 3-to-1 compound and the 7-to-1 engine, but the authors seem to have forgotten their original purpose and the only later reference to this comparison is an incidental remark on page 183 to the effect that "In a comparison of the 7-to-1 with the 3-to-1 compound all efficiencies seem to favor the larger cylinder ratio." This sentence would be entirely overlooked in a hasty search for an answer to the announced purpose of the paper. In the closing paragraph the following reference to the 7-to-1 engine is made: "It is a compound engine thermodynamically misapplied and operated under conditions—ideally at least—defective. It remains to be seen, however, whether with variable load this may not prove on the whole a practically correct and financially efficient system." Presumably this comparison is made between the 7-to-1 and the 3-to-1 compounds, and if so it is not a fair statement of the case, because the 7-to-1 engine made very much the better showing. If this comparison is made between the 7-to-1 compound and the triple, then it is misleading, because it is not clearly stated as such and will generally be understood to refer to the compounds.

On page 176 a "conclusion" is announced, but here we look in vain for what we had expected as to the relative merits of the two types of compounds, so that we are left to delve among the figures for what we had hoped would be clearly shown in the conclusion. Most of us read these papers rather hurriedly, and often get but a vague idea of the subject, or pos-

sibly an incorrect idea, unless the author digests it for us and furnishes a condensed summary of the conclusions that seem to follow from the data obtained. These conclusions should be clearly stated and confined to the subjects actually investigated. If theories or opinions are volunteered it should be made clear that they are not based on the results of the experimental investigation if such is the case. Theories are both interesting and useful, but they should not be confused with facts. The paper under consideration is particularly faulty in this respect. Beginning on the nineteenth page, considerable space is devoted to describing "The Requisites" for certain results. Presumably, these deductions are based on the knowledge obtained from the reported experiments, but such does not seem to be the case, as they are totally irrelevant to the subject under investigation, and, what is still worse, some of the theories here elaborated are demonstrated to be false by the reported facts of the tests. This is most noticeable in the third clause of page 171, which reads as follows: "From either point of view, 'drop' between cylinders is evidently not desirable, except at the point of termination of expansion in the low-pressure cylinder before condensation begins, where drop is required to the extent of the sum of the quantities: friction and cylinder condensation wastes, including also, if it exists, leakage." This theory in regard to "drop" is one that the writer has attacked before (vol. xvi., page 184, *Transactions* A. S. M. E.); but on the former occasion his argument was made in part from a theoretical standpoint. The data of the paper under consideration is good evidence on this interesting subject, and certainly seems to disprove the theory just quoted from the twentieth page.

In comparing the diagrams from the two compounds (the 7-to-1 and the 3-to-1), the most conspicuous difference is in regard to the terminal "drop" between the cylinders, and the higher efficiency is with the excessive "drop." If Dr. Thurston has any facts to support his theory it is hoped that he will offer them in his closing discussion. The writer agrees with him fully as to the necessity of drop in the low-pressure cylinder to cover certain losses, but the same reasoning will apply with even more force to the other cylinders, because, as this paper shows clearly, an appreciable part of the free expansion loss due to drop in the high-pressure cylinder is recovered by the improved quality of the steam entering the next cylinder. All the reasons for drop

in the low-pressure cylinder apply to the other cylinders and the additional reason just mentioned. The writer will not here repeat the arguments that he used in the discussion of Mr. Dean's paper referred to below, but will put himself on record as still adhering to the position then taken.

Referring again to the twentieth page of the paper under consideration, and the paragraph relating to "drop," the latter half of this paragraph reads as follows: "From either point of view, also, compression to boiler pressure with minimum dead spaces and minimum clearance, is requisite." There having been no investigation of the effect of comparison in the reported trials of the Sibley College engine it would be interesting to know what facts Dr. Thurston can give in support of his compression theory.

This question was discussed in connection with Mr. Dean's paper on page 186, vol. xvi., *Transactions* A. S. M. E., and in that discussion reference was made to the investigation conducted by Professor Jacobus, and reported by him in a paper presented at the Montreal meeting of this Society. That investigation showed clearly that the best economy was not obtained by compressing to boiler pressure. Mr. Dean's reply to that discussion contained no facts in support of his theory, and he was content to rest his case by saying that the engine used for the Jacobus test had large clearance, etc. Possibly Dr. Thurston may be better supplied with facts to support his theory, but if not he will hardly take the ground that what is true of an engine with large clearance is not true in any degree with a smaller clearance.

Mr. George I. Rockwood.—Dr. Thurston's paper is full of interest to all steam engineers. The main object of the paper, perhaps, may be said to be to discuss that type of engine which is intermediate between the regular compound, of two cylinders, and the regular compound having three cylinders.

So far as I know, this intermediate type of compound engine was not in existence six years ago, although the idea was partially exhibited in the design of certain marine engines, notably by those in the ships of Messrs. F. Leyland & Company, of Liverpool, who adopted them some ten years ago. I say "partially," because the engines were too small for their boilers, and hence were run at a cut-off so late in the stroke that the free expansion loss was relatively very large, a fact which gave these

engines a worse name than they were entitled to, and prevented the spread of the adoption of this type in steamships. It has appeared to me that the unsteady motion of a large set of such engines, which would be likely to accompany them when at work with full boiler pressure and an early cut-off, would tend greatly to render them unpopular aboard passenger ships.

Certainly, however, it is true that this type of engine was not to be found at work anywhere on land six years ago. It is not strange, therefore, that the proposition to abandon the use of the intermediate cylinder of triple compound engines, advanced in the fall of 1891, was condemned spontaneously as wrong in principle by all the profession who took an interest in it; nor is it altogether to be wondered at that its progress has been regarded with suspicion. I think, however, that with the tests of several examples of this new type of engine before us, and in the light of the good work these engines continue to do, the time has come to admit the intermediate compound to good standing in the fellowship of engines.

With the exception of what I have been able to do in the same direction, Dr. Thurston's paper presents an account of the first competent experimental investigation of the correct place which the intermediate compound should hold in the general theory of the compound steam engine. Although it is rather belated, I warmly welcome it as such.

The discussion of the data is rather confusingly mixed with the author's views of the relative standing of three well-known engines; but the paper is written with so much care that a close study will reveal where his views on the theory of the multiple-cylinder engine are based on the Sibley College experiments, and where on the tests of these three other unrelated engines. In a study of the paper the fact should be kept in mind that the deductions of Dr. Thurston from a consideration of the relative economies of the three different types of engines—the Natick, the Allis, and the Louisville—are contradictory to his deductions from the data of the Sibley College engine tests. It is unnecessary for me to do more than refer to the fact that I disagreed wholly with the comparisons instituted by Dr. Thurston between the Natick, Milwaukee, and Louisville engines, in the discussion of Mr. Dean's paper, vol. xvi, page 184, and which comparison he transposes from that paper into the present one. My comparisons, as given and published in the discussion on

that paper, whether actually true or erroneous, I still consider to be correct, and I still hold to them.

The principal value of this paper to me lies, not in these comparisons, but in that portion of it which is devoted to the very keen analysis of the trials of the Sibley engine. One feature of great interest is the investigation, by aid of the indicator diagrams, into the effect of drop on cylinder condensation. After giving the figures for the quality of the steam, Dr. Thurston says on page 177: "Although with drop there is a marked increase in the range in temperature when calculated from the increased range of pressure in the high-pressure cylinder, the liberated heat from the expanded steam in the high-pressure exhaust is sufficient to make up for this increased pressure range, and to give even a slightly improved quality at the high-pressure point of cut-off. This liberated heat also has the effect of superheating the steam, and thus of lessening the internal loss in the low-pressure cylinder. There is also a gain of work, owing to the absence of an intermediate cylinder whose clearance volume exceeds that of the high-pressure cylinder in the ratio of the squares of their respective diameters." The curves given in Fig. 47 also show the remarkable extent to which an increase of drop increases the quality of the steam. The author proceeds to remark that the gain by expansion in the intermediate cylinder is sufficient to offset these good effects of drop in the case of the Sibley engine. This is valuable information in kind, for it shows how far one may proceed in increasing drop before it becomes a net loss to go further by reason of the increase in free expansion loss. It shows this, however, only for cases like the Sibley engine; cases where the steam pressure is but 115 pounds and the vacuum 22.84 inches. I regret that the conditions of steam pressure and vacuum obtaining throughout these tests were not more representative of the best practice of to-day. If a boiler pressure of 160 pounds had been available, and if the vacuum had been 27 inches or more, the results would have been rendered of far greater general interest. The low boiler pressure and excessive drop are circumstances which prevent the general application of conclusions drawn from these data to engines working under more favorable conditions. Thirty pounds of drop is a much more serious handicap to an engine having a cylinder ratio of 7/1, when working with a boiler pressure of 115 pounds, than it would be if the pressure

was 160 pounds. I think investigations like this, however, are particularly valuable to establish the precise point beyond which drop must not be carried, and I hope we may be favored with more such experimental data.

I should say that the general principle to be followed in the design of an "intermediate compound" could be stated thus: When the "gap" due to "drop" exceeds the "gap" due to greater cylinder condensation, greater clearance, and to the wire-drawing action of the ports of the intermediate cylinder, then "drop" becomes a net loss.

On page 173 Dr. Thurston states his conclusions from a comparison of the data yielded by the Sibley engine, run in the three different ways, in the following words: "In conclusion, these comparisons, after making all allowances, show an economy in favor of the triple, when compared to the 7-to-1 compound, of over one pound of steam per horse-power per hour, and a larger gain by the latter when compared to the compound engine of 3-to-1 ratio. The bearing of these results, however, on the relative merits of the three types, is a matter which experiment on one engine and under one set of conditions cannot definitely determine. As tests have been made of the triple-expansion engine under all systems of jacketing, there is no room for improvement in this direction. In the 7-to-1 compound, however, a change in the jackets, and even more probably a change in the size and distribution of the receiver volumes, might reduce, if not nearly bridge over, the gap which at present separates it, so far as steam consumption is concerned, from the triple-expansion engine." This last statement is an important admission. I think the truth of it would be still more evident if the diagram on Fig. 44 were altered a little in respect of the position of the triple curve. If the curve were to be drawn through the actual points of the tests it would be seen to hug the curve of the 7-to-1 compound quite closely, but forming a hook at its lowest points. Perhaps the disturbing influence which causes this sudden increase of efficiency in the triple might produce the same effect in the compound if present at its trials. I presume the triple had a better vacuum, or drier steam, or perhaps an accidental improvement in radiation, to account for the peculiar shape of the actual curve.

The comparison of the combined indicator cards in Fig. 45 is valuable, and I do not see why it may not be regarded as con-

clusive evidence of the substantially equal economy of the two types of engine. If one measures the shaded portions belonging, respectively, to each engine, but neglects the lowest shaded portion, representing the advantage of the triple due to a better vacuum, and neglects also the shaded portion at the top, representing the advantage of the compound due to a little higher steam pressure, it will be found that the compound is considerably ahead. The triple would undoubtedly nullify this advantage if its temperature range were lessened by the difference in vacuum, as Dr. Thurston points out at the bottom of page 166.

At the end of the paper Dr. Thurston alludes to the first-rate performance of the compound Allis engine at the Warren Manufacturing Company's mill in Rhode Island, as representative of the best work of a mill engine of the "orthodox compound" type. Now, as a matter of fact, this engine has a cylinder ratio quite a good deal larger than the "orthodox" ratio of 1-to-3.5. That is to say, instead of having a low-pressure diameter of 68 inches, the diameter of this cylinder, to represent common practice, would have to be 59 inches; the difference makes the actual ratio, 1-to-4.7, larger by an increase of 34 per cent. The engine is also of huge size, compared with any existing example of the intermediate type of compound engine. But over against the steam consumption per horse-power of this engine let me put that of the Grosvenor Dale 18-inch and 48-inch by 48-inch cross-compound engine. The Warren engine is said to use 12.5 pounds. The Grosvenor Dale engine requires only 11.9 pounds, although of but one-third the power; this with but 143 pounds steam pressure. This result, which—according to the report of Mr. Barrus which is published in a recent number of a technical journal *—is accompanied with a coal consumption of 1.18 pounds, presses closely on the heels of the Leavitt and Reynolds engines. In fact, this engine undoubtedly surpasses them both in economy per delivered horse-power. Why, then, is it not unfair to call it an "engine thermodynamically misapplied, and operated under conditions—ideally, at least—defective?" It is neither a "mutilated" triple compound, nor is it an abnormal instance of an ordinary "orthodox" compound. It is a type by itself, standing at the head of all engines of whatever type, so far as our experience goes, up to date.

* *The Engineering Record*, issue of November 20th, and supplement of paper under discussion.

Mr. John H. Barr.—About the time the experiments of Messrs. Brinsmade and Harding were being planned, Dr. Amsler (then a fellow in Sibley College) undertook an investigation along lines which were suggested by me as the result of speculation upon the advantages and disadvantages of Mr. Rockwood's system. It appeared that the principal mechanical and thermal gain by the latter system over the ordinary triple was (under steady load) due to the smaller clearance loss; next in importance is the saving from reduced wire-drawing between the cylinders; while the drying of the steam by free expansion during drop at release in the high-pressure cylinder is an incidental but small source of gain. Under a load varying through wide range, a great drop at high-pressure release permits considerable change in the point of cut-off without either looping at the end of expansion in the first cylinder or materially changing the receiver pressure. Owing to this last feature, it seems possible that such an engine may give favorable results under varying load, even if its best performance is inferior to the best performance of a corresponding triple-expansion engine. The disadvantages of the two-cylinder engine, as compared with the triple, are the increased cylinder condensation, and the mechanical loss due to the considerable drop after high-pressure release. For comparison, the records of trials of the Sibley College triple-expansion engine were used as data. Diagrams, which it was assumed would approximately represent the corresponding two-cylinder type, were then constructed.

The resulting graphical work is very similar in appearance to Fig. 45 of the present paper, except that the initial and exhaust pressures were kept constant for all cases. It was assumed that the receiver pressure with the two-cylinder type remained the same as for the last receiver in the triple; that initial condensation in the high-pressure cylinder increased in the ratio of the increase of temperature in that cylinder, and that the accompanying greater re-evaporation would give the same quality at exhaust as with the triple. This last assumption may not be entirely warranted, but inspection of Fig. 45 shows a similar result from actual trials.

When the second cylinder is cut out, if the point of cut-off in the high-pressure cylinder remains unchanged, the additional initial condensation requires a greater quantity of steam to fill the cylinder up to cut-off. The loss thus incurred in the first

cylinder is partially compensated for by the larger quantity of steam admitted to the last cylinder, in which the condensation presumably is not much different than with the triple.

The effect of the free expansion in drying the steam was found to be small. Without going into further details the results will be given.

RESULTS.

Unjacketed Engine.

Triple :	I. H. P. = 140.2 ;	Water Rate = 15.78
Two Cylinders :	I. H. P. = 141.0 ;	" " = 18.86
Triple :	I. H. P. = 46.1 ;	" " = 19.92
Two Cylinders :	I. H. P. = 57.4 ;	" " = 20.10

Jacketed Engine.

Triple :	I. H. P. = 141.4 ;	Water Rate = 15.37
Two Cylinders :	I. H. P. = 152.0 ;	" " = 15.58
Triple :	I. H. P. = 45.6 ;	" " = 17.70
Two Cylinders :	I. H. P. = 47.7 ;	" " = 16.80

Prof. Horace B. Gale.—The points in this paper to which I wish to call attention have been already touched upon by Mr. Ball and Mr. Rockwood, but not as emphatically as it seems to me is justified by the importance of the subject. They are expressed in the following paragraph (page 171), which I quote :

"From either point of view, 'drop' between cylinders is evidently not desirable, except at the point of termination of expansion in the low-pressure cylinder before condensation begins, where drop is required to the extent of the sum of the quantities : friction and cylinder-condensation wastes, including also, if it exists, leakage. From either point of view, also, compression to boiler pressure, with minimum 'dead spaces' and minimum clearance, is requisite. In either class of engine the machine acts as a whole, and is to be treated as if the work at the crank-shaft were performed as indicated in the combined diagram, in the case of the multiple-cylinder engine, precisely as if it were a simple machine."

This question of "drop" at the end of the expansion line in the high-pressure and intermediate cylinders of a compound engine has been brought up several times in discussions of the compound engine before this Society.

I remember first advocating the desirability of such a drop in the high-pressure diagram at the Nashville meeting some ten

years ago, in the discussion of a test of a compound engine by Mr. Barrus, and again at the San Francisco meeting in 1892, in the discussion of the paper by Messrs. Green and Rockwood, on "Two-cylinder versus Multi-cylinder Engines."

It has seemed to me as absolutely demonstrable as any proposition in mathematics that such a drop is advantageous.

If the authors of this paper will spend a little time over the mathematics of this question, the fact will be as obvious to them, I believe, as it is to me, that "drop" between cylinders *is* desirable and necessary to attain the highest degree of efficiency. Many able designers seem to have taken for granted that the desideratum in a compound engine is to make composite diagram correspond as closely as possible to the theoretical diagram of a single-cylinder engine having the same initial and final pressures. In so doing, however, they sacrifice a part of the practical advantages in reduction of heat losses which give the compound engine its superiority over the simple engine.

There are several ways of proving this proposition. Here is one. Consider any cylinder of a multi-cylinder engine, working between receivers at two given pressures. It takes steam from a receiver (or the boiler, as the case may be) at a fixed pressure, and delivers it to another receiver (or to a condenser, as the case may be) at a lower fixed pressure. Any one of the cylinders, considered by itself, *is* a simple engine working between a fixed initial and a fixed back pressure. Anything that increases the efficiency of any cylinder, by itself, working between its given pressures, must increase the efficiency of the whole engine, provided, of course, that the change does not affect injuriously the quality of the steam delivered to the following cylinder. Now, it is admitted that the efficiency of a simple engine working between any two fixed pressures *is* increased by permitting a certain "drop" at the end of the expansion line—because such a drop permits the use of a smaller cylinder to do the same effective work, thus diminishing the heat losses and friction losses, each of which increases with the size of the cylinders.

Such a "drop," therefore, will increase the efficiency of *each* cylinder of a multi-cylinder engine, and therefore must improve the performance of all the cylinders together. With the same initial and receiver pressures, the "drop" permits each cylinder to be made smaller, doing the same work, than it could be made

if the expansion were carried down to the back-pressure line. This reduction of size of cylinders saves friction and condensation losses, at the expense merely of the minute triangular areas cut off from the ends of the diagrams of the separate cylinders.

The total area cut off from the composite diagram will be very much smaller, if divided among three small triangles cut off from the tips of the diagrams of the three cylinders of a triple engine, than if concentrated in a single triangle of three times the height, cut off from the end of the low-pressure diagram. This is simply a matter of plane geometry.

It is therefore not true that the total drop can be better (or even equally well) concentrated in the low-pressure diagram.

As to the effect on the steam delivered to the receiver, the drop, or free expansion from cylinder to receiver, so far from injuring, tends slightly to improve the quality, or dryness, of the steam.

These considerations apply to the efficiency of the engine under its ideal conditions of load and pressure, and are independent of the questions of variation of load and cut-off, brought up by Dr. Thurston, and which make desirable *in practice* a considerably greater "drop" between cylinders than is required for maximum efficiency under ideal conditions.

The results of the tests reported to the Society now appear to justify the opinion expressed by the writer in the *Transactions* of 1888 (vol. p.), and he desires again to put on record the proposition that any multi-cylinder engine whose indicator diagrams do not show a "drop" at the end of the expansion in each cylinder, under the ordinary working conditions, is not designed to secure maximum economy, either theoretically or practically.

Similar theoretical considerations, equally well borne out by facts, prove also that the greatest efficiency is attained when the compression is not carried quite up to the initial pressure. The latter point has been so ably presented by Mr. Ball in a recent paper that I will not take time now to discuss it further.

Mr. Rockwood.—I wish to speak in addition upon the point Dr. Thurston raised in commenting on the Grosvenor Dale engine test made by Mr. Barrus. His point was that the best economy attained with this engine was found when the cut-off in the low-pressure cylinder was early instead of late in the

stroke. This, so far as it goes, tends to disprove the results obtained on the Sibley engine, and also to disprove the notion I have entertained that "drop" was a good thing, as this engine did the best with the least amount of drop. But there happen to be in Grosvenor Dale two engines of this type now, one an 18-inch and 44-inch by 72-inch, and the other an 18-inch and 48-inch by 48-inch. You notice the difference is in the diameter of the low-pressure cylinders and in the stroke. The steam pressure is about the same in both cases, and the highest economy was with the engine having the greatest disparity of cylinder volumes.

The point to which I wish to call your attention is, that Mr. Barrus found the best economy with one engine when the cut-off in second cylinder was shortest, and he found precisely the opposite state of affairs with the other engine. In both cases the advantage of one cut-off over another was slight. Now, which engine is to be taken as representing the action of such an engine when working without leakage? I think that different rates of leakage in different parts of engines working with different points of cut-off, will explain inharmonious results, and such is the explanation of the opposite results obtained by Mr. Barrus in these tests. That is to say, the leakage was not the same; neither did it take place at the same points in both engines. So that I do not think Mr. Barrus's experiments, where solely directed to an investigation of the effect of "drop," prove its effects on cylinder condensation, but they show what its total effect is on initial condensation plus a variable leakage. They are valuable because they show that considerable drop may occur without injuring the economy of the engine as a whole.

Prof. Dwelshauvers-Dery.—Professor Thurston, in giving the result of his experiments on the proportioning of the cylinders of multiple engines, has rendered great service to the constructor and to science, according to his usual habit in these matters. It is desirable that other countries should be able to derive benefit from them as well as those only which make use of the English language, and the units of measurement prevailing in these countries. I take it upon myself to contribute with respect to matters appertaining to the French-speaking countries, but I combine with it a request to the author, or those who make reports on the tests of steam engines.

To express the steam consumption of an engine they are accustomed to give the number of pounds of steam per horse-power per hour, as deduced from the experiment itself. Now, a pound of steam has not always the same thermodynamic value; this depends both on the pressure and also on the degree of superheat, as is remarked by Professor Thurston himself on the eighteenth page of his paper in connection with the superheated steam-engine of Schmidt. In fact it is the thermo-units of heat and not of water which the machine consumes, and it ought to be understood that it is the number of thermo-units which is designated under the name of "pound of steam." Without this it will not be possible to make exactly the comparison of the results obtained by different experimenters on engines working at different pressures and different degrees of superheat. The Schmidt engine, with steam highly superheated, would seem, according to the real consumption of steam, to be more than 20 per cent. more economical than the Milwaukee engine. I have made it apparent by the number of thermo-units consumed by each machine per metric horse-power per hour, that these two engines were very nearly equivalent, that of Milwaukee being only about one-tenth of one per cent. in advance. With us in Belgium the custom seems to be likely to establish itself, that the consumption in calories per horse-power per hour, should be obtained, and this should be divided by 655,062, which represents the total heat of a kilogramme of superheated steam at six atmospheres tension. The quotient represents the consumption expressed in kilogrammes of steam, whose definition and quality are exactly given, and which differ evidently more or less from the consumption experimentally measured. This latter has served only to establish the consumption in calories, above stated.

The same result would be obtained if it were agreed to determine the consumption in British thermal units per horse-power per hour in English units, and to call by the term "pound of steam" the number 1,179.1 British thermal units, which represents the total heat of a pound of superheated steam at six atmospheres, or 88.2 pounds per square inch. This experimental number of British thermal units per horse-power per hour, divided by the number 1,179.1, will express the consumption in a style which shall be uniform for all engines.

I have used the term above, "English horse-power per hour,"

because it differs from the metric horse-power per hour whose value is 75 kilogrammeters per second. The English horse-power of 33,000 foot pounds per minute is equivalent to 76.039 kilogrammeters per second. Since the English pound is equivalent to 0.453593 kilogrammes, a consumption of a pound per English horse-power is equivalent to a consumption of 0.4474 kilogrammes per metric horse-power.

Professor Thurston.—The remarks of the first speaker interested us all, and probably have proved somewhat instructive to the members of the Society, as they certainly have to me. His comments upon the paper in general are of a class with comments to which I have become well accustomed in the last twenty years. I think he will modify them, as time goes on, as many others have found reason to do. But, in general, I say that I agree very thoroughly with much that the gentleman adds in his discussion of the paper. There are two or three points, possibly, on which I shall have to make some qualification of my own statements—certainly some qualification of the interpretation which has been put upon them.

As I have said, the question is not so much whether the two-cylinder compound is better than the three, as whether novel proportions are to be adopted where we conclude to use a two-cylinder compound. That, I take it, is the question. Experience shows that there are cases where, other things equal, we certainly would adopt a compound rather than a triple-expansion engine, although the triple-expansion would be the more efficient engine; that is, it would do its work with a smaller consumption of heat, steam, and fuel. Among compound engines which are approaching closely to the efficiency of the triple-expansion engine at the higher pressures, we find some which are doing work so nearly the equivalent of the work of the triple-expansion engine that it becomes a question what are the best proportions for such engines in cases in which it would be perfectly satisfactory to use them in place of the more expensive forms of the triple. I think that is where the main interest attaches to the work of Mr. Rockwood.

Mr. Rockwood speaks of the point noted on page 166—in regard to the way in which the work reported is diagramed. I am inclined to think—as I judge from his remarks he is also—that the curve for the triple-expansion engine should probably lie somewhat higher, which would give added advantage to the

curve assigned to his type of engine. I think this criticism is correct. I am not inclined to lay too much stress on the comparison. I think, as Mr. Rockwood himself has said, that there is a great deal still to be learned. We certainly have learned this much: that most remarkable work has been done by the engine which has these peculiar proportions.

Mr. Ball is inclined to criticise the deductions on page 170.—I remember not very long ago some gentleman made a comment upon some point in a paper which indicated that he had not, carefully certainly, read that particular portion of the paper. If Mr. Ball will re-read page 170, giving special emphasis to the word thermodynamic, in the first line, I imagine he will be led to somewhat modify his comment.

At page 171 a discussion has arisen in regard to the nature of drop as an element in steam-engine design and steam-engine economy. I think that what has been said about drop has been largely correct. I do not think that it necessarily conflicts with the ideas that I have presented. There are cases, unquestionably, many cases very likely, where drop should be shown on indicator diagrams exhibiting the best performance of an engine. The point that I had intended to state was that, nevertheless, drop is not, in itself, a desirable thing. That is to say: as in the case of the steam-jacket, there are many cases where its use is desirable, where it will give large economy; nevertheless it is, intrinsically, a defective device for improving the efficiency of a steam engine, and so the necessity, so often apparent, of introducing drop, in the case of a compound engine, is merely a necessity for introducing an obvious defect—to reduce other defects, if possible, in larger ratio.

We desire, in planning the diagram of a steam engine which represents its thermodynamic operation, to secure from the given amount of heat and steam supplied the largest possible amount of work. That largest possible amount of work is effected by the production, by such an engine, of an engine diagram that shall have no breaks and no losses of area; and in so far as those breaks in the line of the combined diagram, and those losses of area, indicate losses of power, they are the results of defects, and if these particular defects should be found to be necessary, it must be simply because they are a consequence of the existence of other defects in which they are more or less of an antidote.

The remarks of Professor Gale on this point are simply a statement of a well-known fact of a somewhat different sort. That is to say: we know perfectly well that in every engine, if we carry the expansion too far, we produce indicated power at the expense of a greater loss of power in the friction of the engine. We know also that, if we carry our expansion to the extreme, increase of expansion produces an increased waste, due to initial "cylinder-condensation." The drop, which means termination of expansion at comparatively high pressure at the end of the stroke, is a defect introduced to correct other and presumably greater defects. We should seek to remove every defect; but it does not follow that we ought to remove any one defect entirely where its complete removal would introduce a still greater defect. For example: there is always a point beyond which the friction of the engine, or beyond which the condensation of the steam cylinder, has an effect so great as to more than compensate for the amount of increased power that would be obtained by decreasing the amount of drop.

Mr. Ball comments upon another paragraph, reading this line with special emphasis: "From either point of view, also, compression to boiler pressure, with minimum 'dead spaces' and minimum clearance, is requisite." I do not think Mr. Ball himself will object to that statement if he thinks it out carefully, and gives it the weight that those words intend. If we can reduce our dead spaces to absolute minima, and can reduce our clearance to an absolute minimum, then the necessities of wastes in other directions become less. It is desirable both to decrease the clearance and therefore to decrease the necessity either for compression of large volumes of steam, or for considerable drop in order that we may, by combined economies on both sides, secure a maximum total efficiency.

Professor Gale states that each cylinder of the engine should be treated as if it were a separate engine. I do not think that is so at all. The engine, as a whole, turns a crank-shaft, as a whole; and when the engine, as a whole, ceases to develop so much power that the work at the moment is less than that required to overcome the friction of the crank-shaft and the appurtenant frictions of the engine, it is time to cease expansion. From this point of view it is not a matter of very much consequence whether that drop is at the end of expansion of the low-pressure cylinder or distributed through the several cylinders.

For other reasons, it may be well to adopt some drop in each of the cylinders and to distribute this final drop—the quantity of which is made up of the resistance of the engine due to friction, the resistance of the engine due to back pressure, and the loss by cylinder condensation of effect of heat that should be converted into work.

I doubt if any one can say precisely what should be the compression on any one engine until he has used that engine with varying degrees of compression, and has experimentally ascertained where, under its normal load and usual working conditions, compression gives best results. I have just received from Professor Dwelshauvers-Dery, one of our honorary members, who has been experimenting with one of his own experimental engines in Belgium on this subject, and he reports in the last number of the *Revue de Méchanique* that he finds that, with his engine, compression is always objectionable, and that the more he compresses the worse the result.

It certainly remains the fact, after all, that in order to improve the performance of engines it is wise to reduce clearance as far as we can, to reduce *all* conditions that cause waste, and so approximate in every direction to ideal conditions; in other words, as its friends say of football, "Retain the uses and reform the abuses." I have no doubt that, after this subject is somewhat more completely investigated—and it is being very extensively investigated at present—we shall know definitely what to conclude. For myself, I am not inclined to dogmatize in this or any other direction.

*Prof. R. H. Thurston.**—Reviewing the paper and its discussion, I find little to require restatement or reconstruction. A second edition of the paper would, as always is the fact, be capable of improvement in method of statement and by excision and addition; but the main facts are patent, and the conclusions must be made by each for himself; we are all, unquestionably, as ready to permit our colleagues to deduce their own conclusions as to insist upon the same right for ourselves. My own conclusions as to the essential elements of the matter in hand may be stated in most compact form substantially as on page 170 of the paper. They may even be summarized as follows:

(1) The engineer should seek, in his design and constructions

* Author's closure, under the Rules.

of steam engines, to produce, as closely as practicable, the ideal heat-engine cycle.

(2) He should reduce thermodynamic wastes of heat, steam, and fuel by the adoption of a maximum range of, as nearly as practicable, adiabatic expansion, starting from a maximum pressure and terminating, as nearly as practicable, at a minimum back pressure, with full compression.

(3) Where, as in the case of cylinder condensation, an unavoidable cause of waste is met, he should, in its correction by introduction of a new defect, as its antidote, endeavor in part to secure the best compromise; making the sum of the original and newer forms of waste a minimum.

(4) Applying these principles to the case in hand, the indicator diagram should be made to approximate the ideal as closely as practicable, and the limitations due friction and "cylinder condensation" should be removed as far as practicable by superheating steam, by jacketing, and by compounding, in such manner that the sum of the wastes, original and artificial, may be a minimum. Each should aid in removing the thermodynamic and ideal defect—just so far as it is found to pay to do so.

Thus we find that extreme expansion and extreme compression, alike, have practical limitations; "drop" becomes a necessary defect in summing up all defects for a minimum; jackets pay in some cases, while in others they are commercially, even sometimes physically, a defect. Multiple-cylinder engines are demanded and pay well in some instances, simple engines in others, and in many instances the compound may prove, on the whole, better than the triple-expansion engine. Large clearances may be actually needed.

In the paper here under discussion it is shown that, in practice, the "7-to-1 compound" exhibits higher efficiency as its ratio of expansion becomes that suitable to its cylinder proportions. It is seen that, in the cases compared, at least, the compound suited to large expansion ratios approximates closely the best work of the triple-expansion engine, suited to similar ratios, which is compared with it. My own final deduction is, that the difference between the compound and the triple, for high ratios of expansion, and presumably, though not here determined, for high pressures, may be so very small that, in such a doubtful case, it will best pay often, if not generally, to employ the simpler engine.

As to the distinguishing feature of the new form of compound —its large intermediate drop: I think it evident, as already stated in the text, that "drop between cylinders is not desirable." It may be needed as a corrective of excessive clearance; it is certainly needed somewhere—preferably, I should say, at the termination of the expansion in the low-pressure cylinder—as a corrective of wastes by friction, etc., but it is, nevertheless, a defect compelled by the presence of another defect. The true deduction is that *both* defects should be, just as far as practicable, avoided. The ideal case should be approximated, in practice, in every practicable way.

The conclusions on page 170 of the paper, as to the "Requisites of Maximum Efficiency," require no modification in view of the comments made upon them in this discussion.

Referring to the remarks of Professor Dwelshauvers-Dery: The suggestion that the scientific measurement of efficiency is best given in thermal units rather than in pounds of steam, which is made by him, is unquestionably correct. The practice is coming to be usual on this side the Atlantic, and will, in time, I have no doubt, find practically universal adoption. I have myself customarily employed it with the older measure, and its use is illustrated in recent papers. In most cases *both* measures should be given; not only because the practitioner is accustomed to judge engines by the older gauge—which is, in fact, ordinarily a very accurate one—but also because both are needed to give an exact indication of the conditions of operation and of the performance of the machine.

For efficiency unity the extreme range of variation of measure, between even-condensing and non-condensing engines, is usually only between the totals 2.3 to 2.5 pounds of steam per horse-power per hour; while, in the same class, the variation of this unit is commonly insignificant, the temperatures of feed-water being those of good practice. It must not be forgotten, also, that the measure, in thermal units, pei horse-power per hour, is subject, at the boiler, to variation with the variation of the effectiveness of the feed-heating apparatus, and the reported figure may thus be, to a certain extent, misleading. To secure comparable measures, the range of temperature for which this quantity of heat is reported should be reduced to that between the temperatures of boiler steam and condenser o atmospheric steam, for condensing and for non-condensing engines, respec-

tively. Otherwise the efficiency of the steam-making apparatus is involved, and the efficiency of the engine is then stated in variable terms. The true and only accurate measure of the real efficiency of the engine is the quantity of heat, measured in thermal units or the equivalent, per horse-power and per hour, as determined by the measured amount of heat which must be imported into the water in the condenser at the indicated back pressure, to convert it into steam of the temperature, pressure, and quality of that entering the steam chest. The proprietor of the machine is finally mainly concerned to know the proportion of the potential heat-energy of the fuel, for which he spends his dollars, which is made to appear as mechanical energy at the engine-belt, or at the jack-shaft: that is to say, the weight of combustible demanded per dynamometric horse-power per hour, or, in still more intelligible terms, to him, the dollars and cents per horse-power per annum which his utilized power costs him as a total.

In the paper here presented, the efficiencies are measured, in the text, in weight of steam used, partly because the figures are sometimes quoted, partly because the experimental comparison is equally accurate when made on this more generally understood basis. They can be reduced quite accurately by taking the weight 2.3 pounds of steam as corresponding to efficiency unity, corresponding to 2,545 British thermal units per horse-power per hour, and, in the work here reported, substantial accuracy and a correct comparison may be made on this basis by multiplying the figure for the pounds of steam, per horse-power per hour, by 20 to obtain British thermal unit per minute, or by 1,200, the hour being taken as unit of time. The figures suggested as desirable are, in this paper, given in Appendix A, and, if desired, can be reduced, as just indicated, for Appendix B.

DCCLXI.*

THE LAW OF HYDRAULIC OBSTRUCTION IN CLOSED STREAMS.

BY DAVID GUELBAUM, SYRACUSE, N. Y.

(Junior Member of the Society.)

THE class of phenomena here considered are such as are presented in Fig. 50. A stream is enclosed in a conduit casing with an upset, or change of section, and passes around an obstruction placed at some distance from the upset. Notwithstanding the frequency with which these phenomena are met with in practice, they have been and are still a problem standing, as yet, unsolved ; and even in the simple case of a stream within a clear pipe passing around a flat baffle, the contraction of the stream and its effective pressure upon the baffle are as yet unknown both experimentally and theoretically. The establishment, therefore, of a law governing these phenomena, or of a general property common to all of them and affording a basis for a general solution of these problems, would be a decided gain. After certain investigations, I discovered such a common and very remarkable property, which I would call the "law of hydraulic obstruction in closed streams." I see no other way of demonstrating that law but by rendering here the method of investigation which led me to its discovery.

I.

Let Fig. 51 represent a pipe with an upset of diameters, respectively d and d_1, and a flat baffle inside with a stem of diameters, respectively, d_0, d_2, and d_3, as marked on the sketch. Through this pipe, water is being forced with initial velocity v under initial pressure p. Let the resultant of the total reactive pressure of the baffle plate, on either side of it, upon the water be denoted by P_1 and P_2 ; and the resultant reactive pressure of the upset by p_m and p_n per unit of the respective concentric

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

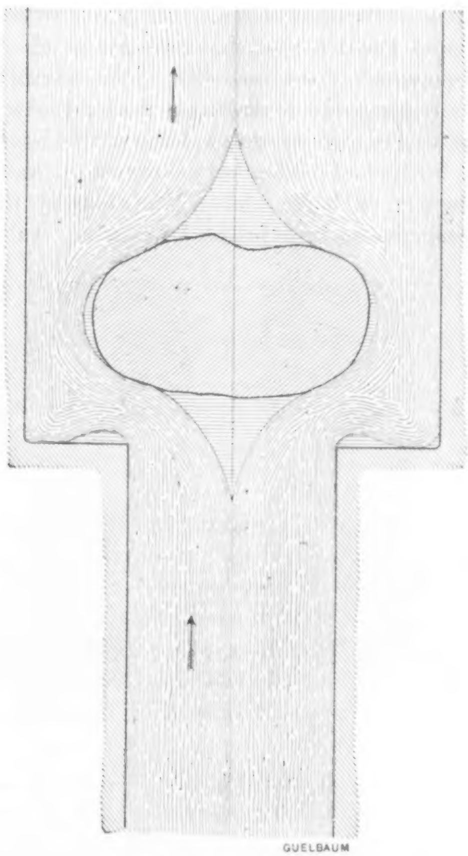


FIG 50.

areas indicated on the sketch. Then, for the mass of water enclosed between the sections AA and BB, at and outside of which the stream runs in a straight current parallel to the axis of the pipe, the condition of equilibrium at settled uniform motion will be:

$$p\frac{\pi}{4}(d^2 - d_2^2) + p_m\frac{\pi}{4}(d_0^2 - d^2) + p_n\frac{\pi}{4}(d_1^2 - d_0^2) - p_1\frac{\pi}{4}(d_1^2 - d_3^2)$$

$$- \rho\frac{\pi}{4}(d^2 - d_2^2)(H_1 + fH_1) - \rho\frac{\pi}{4}(d_1^2 - d_2^2)(h + fh) - \rho\frac{\pi}{4}(d_1^2 - d_0^2)$$

$$(e + fe) - \rho\frac{\pi}{4}(d_1^2 - d_3^2)(e_1 + fe_1 + H_2 + fH_2) + \rho\frac{\pi}{4}(d^2 - d_2^2)\frac{v}{g}(v - v_1)$$

$$= P_1 - P_2.$$

Here the first term expresses the pressure in section *AA*; the second and third terms, the pressure of the upset; fourth term, the pressure in section *BB*; fifth, sixth, seventh, and eighth terms express the retarding action of gravity and friction of the masses of water enclosed between the sections *AA* and *CC*, *CC* and bottom of baffle, between bottom and top of baffle, and between top of baffle and *BB*; whereby the friction in each of these masses is expressed in an equivalent weight of

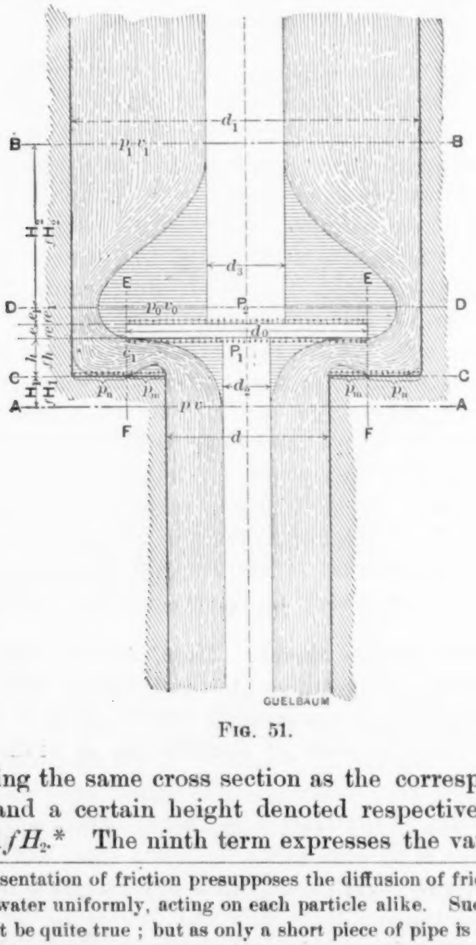


FIG. 51.

water having the same cross section as the corresponding mass of water and a certain height denoted respectively by fH_1, fh, fe, fe_1, and fH_2.* The ninth term expresses the variation in the

* Such presentation of friction presupposes the diffusion of friction all through the mass of water uniformly, acting on each particle alike. Such supposition of course cannot be quite true; but as only a short piece of pipe is being considered here, the friction will amount to very little, anyway, compared with other forces, and is being introduced only to ascertain its possible influence, and will disappear later on by itself.

quantity of motion between the sections AA and BB per second. The last term represents the resultant reactive pressure of the baffle upon the water; *i.e.*, the *total* load necessary to apply to the stems d_2 and d_3 to keep the baffle in place against the current. This equation will be more convenient as presented below:

$$(1)\ldots\left\{\begin{array}{l} \dfrac{p-p_1}{\rho}+\dfrac{p_m-p_1}{\rho}\dfrac{d_0^2-d^2}{d^2-d_2^2}+\dfrac{p_n-p_1}{\rho}\dfrac{d_1^2-d_0^2}{d^2-d_2^2}+\dfrac{p_1}{\rho} \\ \dfrac{d_3^2-d_2^2}{d^2-d_2^2}+\dfrac{v}{g}(v-v_1)-(H_1+fH_1)-\dfrac{d_1^2-d_2^2}{d^2-d_2^2}(h+fh) \\ -\dfrac{d_1^2-d_0^2}{d^2-d_2^2}(e+fe)-\dfrac{d_1^2-d_3^2}{d^2-d_2^2}(e_1+fe_1+H_2+fH_2) \\ =\dfrac{P_1-P_2}{\rho\dfrac{\pi}{4}(d^2-d_2^2)}. \end{array}\right.$$

Let c_1 denote the resultant vertical projection of the velocity of the stream when it passes the cylindrical surface $\pi d_0 h$, on line EF, as marked on sketch; and v_0 the vertical velocity of the stream at its most contracted section DD after it passed the baffle. Then the equation of equilibrium for the mass enclosed between the horizontal sections CC and DD, outside of the cylindrical surface EF, will be as follows:

$$p_n\frac{\pi}{4}(d_1^2-d_0^2)-\rho\frac{\pi}{4}(d_1^2-d_0^2)(h+fh+e+fe+e_1+fe_1)$$
$$+\rho\frac{\pi}{4}(d^2-d_2^2)\frac{v}{g}(c_1-v_0)-p_0)\frac{\pi}{4}(d_1^2-d_0^2)=0.$$

Here the first term expresses the reactive pressure of the upset upon the mass of water; the second, the retarding action of gravity and friction; the third, the variation in the quantity of motion per second between the sections EF and DD, and the last term, the back pressure in section DD. This equation, too, will be more convenient as presented below:

$$\frac{p_n-p_1}{\rho}\frac{d_1^2-d_0^2}{d^2-d_2^2}-\frac{p_0-p_1}{\rho}\frac{d_1^2-d_0^2}{d^2-d_2^2}+\frac{v}{g}(c_1-v_0)$$
$$-\frac{d_1^2-d_0^2}{d^2-d_2^2}(h+e+e_1)(1+f)=0\ldots\ldots\quad(2)$$

Beside the above two we have still the regular Danillo Bernouilli equations, one for sections AA and BB:

$$\frac{p}{\rho} + \frac{v^2}{2g} = \frac{p_1}{\rho} + \frac{v_1^2}{2g} + Y_1 + \left(\frac{d^2 - d_2^2}{d^2}\right)^2 \left(1 - \frac{d^2}{d_1^2}\right)^2 \frac{v^2}{2g}$$
$$+ (H_1 + h + e + e_1 + H_2)(1 + f) = 0 \quad . \quad . \quad . \quad . \quad (3)$$

Here Y_1 denotes the loss of height between sections AA and BB, *due to the presence of baffle only;* to this, therefore, is to be added the loss by impact from the upset at absence of baffle, which is equal to:

$$\frac{1}{2g}\left(\frac{d^2 - d_2^2}{d^2} v - \frac{d_1^2 - d_3^2}{d_1^2} v_1\right)^2 = \frac{1}{2g}\left(\frac{d^2 - d_2^2}{d^2} v - \frac{d_1^2 - d_3^2}{d_1^2} \frac{d^2 - d_2^2}{d_1^2 - d_3^2} v\right)^2$$
$$= \left(\frac{d^2 - d_2^2}{d^2}\right)^2 \left(1 - \frac{d^2}{d_1^2}\right)^2 \frac{v^2}{2g}\text{; and also the loss by friction is added.}$$

Another Bernouilli equation for sections DD and BB will be:

$$\frac{p_0}{\rho} + \frac{v_0^2}{2g} = \frac{p_1}{\rho} + \frac{v_1^2}{2g} + \frac{(v_0 - v_1)^2}{2g} + H_2 + fH \quad . \quad . \quad . \quad (4)$$

This completes the fundamental elementary equations forming the basis for further constructions.

Subtracting equation (2) from equation (1), and excluding $(p - p_1)$ and $(p_0 - p_1)$ by means of equations (3) and (4), we obtain one following equation:

$$\frac{P_1 - P_2}{\rho \frac{\pi}{4}(d^2 - d_2^2)} = Y_1 + \frac{d_0^2 - d^2}{d^2 - d_2^2}\left[\frac{p_m - p_1}{\rho} - (h + e + e_1 + H_2)(1 + f)\right]$$
$$+ \frac{d_3^2 - d_2^2}{d^2 - d_2^2}\left[\frac{p_1}{\rho} + (e + e_1 + H_2)(1 + f)\right] + \frac{d_0^2 - d_3^2}{d^2 - d_2^2}(e + fe)$$
$$- \left(\frac{v^2}{2g} - \frac{v_1^2}{2g}\right) + \left(\frac{d^2 - d_2^2}{d^2}\right)^2 \left(1 - \frac{d^2}{d_1^2}\right)^2 \frac{v^2}{2g}$$
$$+ \frac{d_1^2 - d_0^2}{d^2 - d_2^2}\left[-\frac{v_0^2}{2g} + \frac{v_1^2}{2g} + \frac{(v_0 - v_1)^2}{2g}\right] + \frac{v}{g}(v - c_1) + \frac{v}{g}(v_0 - v_1).$$

Simplifying the third term from the end and the last one, as follows:

$$+ \frac{d_1^2 - d_0^2}{d^2 - d_2^2}\left[-\frac{v_0^2}{2g} + \frac{v_1^2}{2g} + \frac{(v_0 - v_1)^2}{2g}\right] + \frac{v}{g}(v_0 - v_1)$$
$$= -\frac{d_1^2 - d_0^2}{d^2 - d_2^2}\frac{v_1}{g}(v_0 - v_1) + \frac{v}{g}(v_0 - v_1) = -\frac{d_1^2 - d_0^2}{d^2 - d_2^2}\frac{d^2 - d_2^2}{d_1^2 - d_3^2}\frac{v}{g}(v_0 - v_1)$$
$$+ \frac{v}{g}(v_0 - v_1) = \frac{v}{g}(v_0 - v_1)\left(1 - \frac{d_1^2 - d_0^2}{d_1^2 - d_3^2}\right) = + \frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\frac{v}{g}(v_0 - v_1);$$

and dividing all terms by $\frac{v^2}{g}$, the above equation can be written as below:

$$
(5)\ldots\left\{
\begin{aligned}
&\frac{P_1 - P_2}{\rho \frac{\pi}{4}(d^2 - d_2^2)\frac{v^2}{g}} - \frac{d_3^2 - d_2^2}{d^2 - d_2^2}\left[\frac{p_1}{\rho \frac{v^2}{g}} + \frac{(e + e_1 + H_2)}{\frac{v^2}{g}}(1 + f)\right] \\
&- \frac{d_0^2 - d_3^2}{d^2 - d_2^2}\left(\frac{e + fe}{\frac{v^2}{g}}\right) + \left(\frac{v^2}{2g} - \frac{v_1^2}{2g}\right)\frac{1}{\frac{v^2}{g}} - \left(\frac{d^2 - d_2^2}{d^2}\right)^2\left(1 - \frac{d^2}{d_1^2}\right)^2\frac{1}{2} \\
&= \frac{1}{\frac{v^2}{g}}Y_1 + \frac{d_0^2 - d^2}{d^2 - d_2^2}\left[\frac{p_m - p_1}{\rho \frac{v^2}{g}} - \frac{h + e + e_1 + H_2}{\frac{v^2}{g}}(1 + f)\right] \\
&+ \frac{v - c_1}{v} + \frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\frac{v_0 - v_1}{v}.
\end{aligned}
\right.
$$

In above equation (5) the first term has for its denominator the initial quantity of motion of the entering stream per second; the second and third terms represent the statical pressure upon the baffle which would exist if the water could be stationary, with the addition only of friction due to motion; the fourth and fifth terms express the pressure upon the baffle due to the change of the initial velocity from v into the final velocity v_1; that is, this pressure is caused by the upset only of the pipe from diameter d to diameter d_1, and this change of pressure between sections AA and BB would be the same if there would be no obstructing baffle inside. Therefore, the sum total of the first part of equation (5) represents the pressure upon the baffle per unit of initial quantity of motion due to presence of baffle only; this pressure per unit quantity of motion we will designate by one letter P.

In the second part of equation (5) the first term, $\frac{1}{\frac{v^2}{g}}Y_1$ represents the loss of height per unit of initial quantity of motion due to presence of baffle only; we will designate this by one letter Y. The second and third terms express the condition of the stream at entrance between baffle and seat, and we will designate them by one variable z; this is that unknown quantity which determines the pressures P_1 and P_2 upon each side of the

baffle separately, because from the condition of equilibrium of the mass enclosed between AA and bottom of baffle inside of EF, after excluding $\frac{p}{\rho}$ by means of equation (3), we have :

$$z + \frac{d_0^2 - d_2^2}{d^2 - d_2^2}\left[\frac{p_1}{\rho\frac{v^2}{g}} + \frac{e + e_1 + H_2}{\frac{v^2}{g}}(1 + f)\right] - \frac{1}{\frac{v^2}{g}}\left(\frac{v^2}{2g} - \frac{v_1^2}{2g}\right)$$
$$+ \tfrac{1}{2}\left(\frac{d^2 - d_2^2}{d^2}\right)^2\left(1 - \frac{d^2}{d_1^2}\right)^2 + Y = \frac{P_1}{\rho\frac{\pi}{4}(d^2 - d_2^2)\frac{v^2}{g}} \quad . \quad . \quad (\alpha)$$

Here all terms are known but z, Y, and P_1. In the last term, in equation (5), the factor $\frac{v_0 - v_1}{v}$ expresses the relative contraction of the stream past the baffle, and we will designate it by one variable x. Hence equation (5) can be written in the following shape :

$$P - Y = z + \frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(I)}$$

Of the two variables z and x, only z will be treated as an independent one, because when the condition of the stream between baffle and seat is given its further course is already fixed.

Concerning Y—the loss of height from presence of baffle per unit of initial quantity of motion—it will consist, first, of the possible impacts and horizontal frictions taking place between baffle and seat ; and second, of the impact past the baffle. The last one depends only upon the contraction at section DD and is equal to $x^2\frac{v^2}{2g}$; the first one is uncertain, and by analogy we will designate it by $y^2\frac{v^2}{2g}$, so that

$$Y = \frac{x^2}{2} + \frac{y^2}{2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(II)}$$

II.

I will now apply the principle of least work, or least resistance. This will be expressed in the condition :

$$P = \text{const.}; \frac{dY}{dz} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

This simply means, that in case of a baffle with a fixed load upon it, of all the possible adjustments of the stream between baffle and seat balancing the load, that adjustment will prevail at which the loss Y is minimum; or, $\frac{dY}{dz} = 0$. From the fact that at uniform initial velocity of the stream the external forces applied here are constant, it may justly be inferred that the case here considered ought to be one of stable equilibrium, which is possible only at minimum Y, provided the function of Y is such that it admits of a condition of minimum. That such is the case the following will show:

Based on condition (6) we have from equations (I) and (II) by differentiation:

$$0 = 1 + \frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\frac{\delta x}{\delta z}; \quad 0 = x\frac{\delta x}{\delta z} + y\frac{\delta y}{\delta z}; \text{ or}$$

$$\frac{\delta x}{\delta z} = -\frac{d_1 - d_3}{d_0^2 - d_3^2} = -\frac{y}{x}\frac{\delta y}{\delta z}; \text{ or } x = \frac{d_0^2 - d_3^2}{d_1^2 - d_3^2} y \frac{\delta y}{\delta z}.$$

Excluding Y from (I) and (II) and determining x, we will have:

$$x = \frac{d_0^2 - d_3^2}{d_1^2 - d_3^2} y \frac{\delta y}{\delta z} = -\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2} \pm \sqrt{\left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 - 2z - y^2 + 2P}; \text{ or}$$

$$\pm \sqrt{\left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 + 2P - y^2 - 2z} = \tfrac{1}{2}\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\frac{d(2z + y^2)}{dz}; \text{ or}$$

$$\tfrac{1}{2}\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\int \frac{d(2z + y^2)}{\sqrt{\left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 + 2P - (2z + y^2)}} = \pm \int dz; \text{ hence}$$

$$-\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\sqrt{\left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 + 2P - 2z - y^2} = \pm (z + c). \quad . \quad (7)$$

Determining $(z + c)$ from equation (7) and from equation (I) and replacing y^2 by $2Y - x^2$, we get:

$$z + c = -\left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 \pm$$

$$\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\sqrt{2\left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 + 2P + 2c - 2Y + x^2}$$

$$= P - Y - \frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}x + c; \text{ or,}$$

$$\left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 \left[2\left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 + 2P - 2Y + 2c + x^2\right]$$
$$= \left[P - Y - \frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}x + \left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 + c\right]^2.$$

Developing the last equation, we have:

$$(P - Y)^2 + 2(P - Y)\left[c - \frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}x\right] + c^2 - 2c\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}x$$
$$- 2\left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^3 x - \left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^4 = 0.$$

Adding and subtracting to last equation $\left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}x\right)^2$, we obtain:

$$\left[P - Y + c - \frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}x\right]^2 - \left[\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}x + \left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2\right]^2 = 0;$$

or,

$$(8) \quad . \quad . \quad . \quad \left[P - Y + c + \left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2\right]$$
$$\left[P - Y - 2\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}x - \left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 + c\right] = 0.$$

Which of the two factors in equation (8) is zero can be decided in the following way: Subtracting equation (3) from (1) and making the usual modification, we obtain:

$$(\beta) \quad . \quad . \quad P - Y = \frac{d_0^2 - d^2}{d^2 - d_2^2}\frac{p_m - p_1}{\rho\frac{v^2}{g}} + \frac{d_1^2 - d_0^2}{d^2 - d_2^2}\frac{p_n - p_1}{\rho\frac{v^2}{g}} +$$
$$\frac{v - v_1}{v} - \frac{d_1^2 - d^2}{d^2 - d_2^2}\frac{h + e + e_1 + H_2}{\frac{v^2}{g}}(1 + f).$$

At a position of baffle far away from the upset, p_m and p_n will become equal to p — the initial pressure of the entering stream, while at position of baffle near by the upset, p_m and p_n will be less than p on account of increased velocities and loss of pressure through resistance. Hence the second part of equation (β) will vary with different positions of the baffle, and $P - Y$ cannot be a constant; therefore in equation (8) the second factor only can be zero; *i.e.*:

$$P - Y = 2\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}x + \left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 - c \quad . \quad . \quad . \quad (9)$$

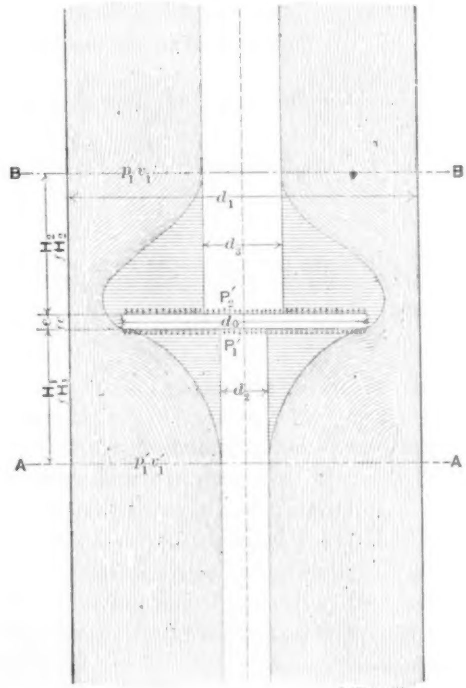


FIG. 52.

The unknown arbitrary term c in equation (9) can be replaced by a more comprehensive one. Let Fig. 52 represent the same baffle within the same casing as in Fig. 51, only removed at such a distance h_0 from the upset that the latter ceases to influence the passage of the stream around the baffle, so that the case becomes practically one of a baffle within a clear pipe. Then the condition of equilibrium for the mass enclosed between AA and BB, retaining the same notations as in equation (1), will be:

$$p_1{}^1 \frac{\pi}{4}(d_1^2 - d_2^2) - p_1 \frac{\pi}{4}(d_1^2 - d_3^2) - \rho \frac{\pi}{4}(d_1^2 - d_2^2)(H_1 + fH_1)$$
$$- \rho \frac{\pi}{4}(d_1^2 - d_0^2)(e + fe) - \rho \frac{\pi}{4}(d_1^2 - d_3^2)(H_2 + fH_2)$$
$$+ \rho \frac{\pi}{4}(d_1^2 - d_2^2) \frac{v_1{}^1}{g}(v_1{}^1 - v_1) = P_1{}^1 - P_2{}^1;$$

or, as modified below and divided by $\rho \frac{\pi}{4}(d^2 - d_2^2)$:

$$\left[\frac{p_1^1 - p_1}{\rho} - (H_1 + e + H_2)(1 + f)\right]\frac{d_1^2 - d_2^2}{d^2 - d_2^2}$$
$$+ \left[\frac{p_1}{\rho} + (e + H_2)(1 + f)\right]\frac{d_3^2 - d_2^2}{d^2 - d_2^2} + (e + fe)\frac{d_0^2 - d_3^2}{d^2 - d_2^2}$$
$$+ \frac{d_1^2 - d_2^2}{d^2 - d_2^2}\frac{v_1^1}{g}(v_1^1 - v_1) = \frac{P_1^1 - P_2^1}{\rho\frac{\pi}{4}(d^2 - d_2^2)}; \quad . \quad . \quad . \quad (1)^1$$

and the Bernouilli equation for the same sections AA and BB:

$$\frac{p_1^1}{\rho} + \frac{v_1'^2}{2g} = \frac{p_1}{\rho} + \frac{v_1^2}{2g} + Y_1^1 + (H_1 + e + H_2)(1 + f). \quad . \quad (3)^1$$

From $(1)^1$ and $(3)^1$ we have, excluding $(p_1^1 - p_1)$:

$$\left(-\frac{v_1'^2}{2g} + \frac{v_1^2}{2g} + Y_1^1\right)\frac{d_1^2 - d_2^2}{d^2 - d_2^2} + \left(\frac{p_1}{\rho} + (e + H_2)(1 + f)\right)\frac{d_3^2 - d_2^2}{d^2 - d_2^2}$$
$$+ (e + fe)\frac{d_0^2 - d_3^2}{d^2 - d_2^2} + \frac{d_1^2 - d_2^2}{d^2 - d_2^2}\frac{v_1'}{g}(v_1^1 - v_1) = \frac{P_1^1 - P_2^1}{\rho\frac{\pi}{4}(d^2 - d_2^2)};$$

or, as below:

$$\frac{P_1^1 - P_2^1}{\rho\frac{\pi}{4}(d^2 - d_2^2)\frac{v^2}{g}} - \frac{d_3^2 - d_2^2}{d^2 - d_2^2}\left(\frac{p_1}{\rho\frac{v^2}{g}} + \frac{e + H_2}{\frac{v^2}{g}}(1 + f)\right) - \frac{d_0^2 - d_3^2}{d^2 - d_2^2}\frac{e + fe}{\frac{v^2}{g}}$$
$$+ \frac{d_1^2 - d_2^2}{d^2 - d_2^2}\left(\frac{v_1'^2}{2g} - \frac{v_1^2}{2g}\right)\frac{1}{\frac{v^2}{g}} = \left(1 + \frac{d_1^2 - d^2}{d^2 - d_2^2}\right)\frac{1}{\frac{v^2}{g}}Y_1^1$$
$$+ \frac{d_1^2 - d_2^2}{d^2 - d_2^2}\frac{v_1^1}{v}\left(\frac{v_1^1 - v_1}{v}\right). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)^1$$

Denoting the first part of this equation by P_0, as we did in equation (5), and replacing $\frac{1}{\frac{v^2}{g}}Y_1^1$ by $Y_0 = \frac{x_0^2}{2} + \frac{y_0^2}{2}$, in analogy with equation (II), equation $(5)^1$ can be written as follows:

$$P_0 - Y_0 = \frac{d_1^2 - d^2}{d^2 - d_2^2}\left(\frac{x_0^2}{2} + \frac{y_0^2}{2}\right) + \frac{v_1^1 - v_1}{v}. \quad . \quad . \quad (I)^1$$

The last term is obtained by replacing $\frac{v_1^1}{v}$ by $\frac{d^2 - d_2^2}{d_1^2 - d_2^2}$. Equation $(I)^1$ represents equation (I) with the condition that the dis-

tance h between baffle and upset has reached its limit h_0. At the same limit equation (9) would become:

$$P_0 - Y_0 = 2\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}x_0 + \left(\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}\right)^2 - c \quad . \quad . \quad . \quad (9)^1$$

Subtracting equation $(9)^1$ from (9), we have:

$$P - Y = 2\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}(x - x_0) + P_0 - Y_0.$$

Excluding here the last term by means of equation $(\mathrm{I})^1$, we obtain:

$$(\mathrm{III}) \ . \ P - Y = 2\frac{d_0^2 - d_3^2}{d_1^2 - d_3^2}(x - x_0) + \frac{d_1^2 - d^2}{d^2 - d_2^2}\left(\frac{x_0^2}{2} + \frac{y_0^2}{2}\right) + \frac{v_1^1 - v_1}{v}.$$

It is this equation (III) which I believe to represent the general law of hydraulic obstruction in closed streams. Expressed in words, it says: If an obstruction placed within a stream enclosed in a casing with an upset is changing its position from the limit distance h_0 to the distance h towards the upset, causing thereby a certain variation in the quantity of motions of the contracted stream around the obstruction, then *the difference between the full pressure upon the obstruction and the direct pressure upon it due to loss of height only, equals twice the part of the variation in the quantity of motion that reacts upon the area of the obstruction, plus a certain constant*; pressures and loss of height mentioned being those due to presence of obstruction only.

III.*

In the further investigation to follow, the constant terms $\frac{d_1^2 - d^2}{d^2 - d_2^2}\left(\frac{x_0^2}{2} + \frac{y_0^2}{2}\right)$ and $\frac{v_1^1 - v_1}{v}$ will be dropped from equation (III); both terms will be understood as included in the total pressure P. The separate appearance of these terms is merely due to the fact, that the pressures have all been referred to the initial section of the stream $\frac{\pi}{4}(d^2 - d_2^2)$ in plane AA, Fig. (51), while the pressures due to the loss $(x_0^2 + y_0^2)$ and to the variation $(v^1{}_1 - v_1)$ are actually distributed all through the final section $\frac{\pi}{4}(d_1^2 - d_3^2)$ in plane BB.

* Added after the meeting.

From equation (III) one general conclusion may be made, namely, that in deformations of closed streams, such as produced by a body immersed within the stream, the only source of live pressure, or reaction $(P - Y)$, is the final stream contraction, or impact, x. As the *character* of the deformation remains the same, whether the immersed body is stationary or possesses velocity and acceleration, then, the relation between the reaction and the stream contraction x ought also to remain the same in both cases, and equation (III), therefore, ought to apply to moving obstructions as well as it does to stationary ones. This would not contradict the assumed condition $P =$ constant, of equation (6), in which the load upon the baffle was considered as fixed. Indeed, all the previous equations have nothing to do with the outside forces acting upon the baffle, and P actually means the resultant pressure exerted by the stream upon the baffle, which pressure naturally varies with the position h of the baffle and the adjustment of the stream between baffle and upset. Therefore, the condition $P =$ const. must be given a relative meaning, namely: Whatever pressure P the stream may exercise upon the baffle at the given moment and position, the tendency of the self-adjustment z of the stream will always be towards minimum loss Y, or $\frac{dY}{dz} = O$. In that sense P is being considered as constant while differentiating on z. For the preliminary demonstration of the law, it was simpler, of course, to consider that condition, when the baffle is stationary and its load P in equilibrium with the resultant pressure of the stream passing around the baffle.

If the above general conclusion and its consequence are correct, then the preliminary fundamental equations (1), (2), (3), and (4) must also apply to a closed stream with a moving baffle, and in such a way as to result in an equation similar to equation (I). The following consideration may justify and direct such special application of the equations of equilibrium to the case of a moving and unbalanced baffle within a closed stream.

Let the baffle be moving in the direction of the stream with a velocity $\frac{\delta h}{\delta t}$ at the given moment and position, h denoting the distance of the baffle from the upset. Imagine within the mass of water, below the baffle, a central column of such cross sectional area on line AA, Fig. (51), that the volume of water pass-

ing through it per second in the plane AA is equal to the displacement per second of the baffle at the given moment. The area of such a column would be $\frac{\pi}{4}\frac{(d_0^2 - d_2^2)}{v}\frac{\delta h}{\delta t}$. A similar central column above the baffle would have an area on the line BB, $\frac{\pi}{4}\frac{(d_0^2 - d_3^2)}{v_1}\frac{\delta h}{\delta t}$, v and v_1 being the initial and final velocities of the stream in planes AA and BB. It is evident that equation (2) of equilibrium of the mass of water enclosed between the planes CC and DD outside of the line EF, Fig. (51), cannot apply to the central column, as its mass of water does not pass around the baffle, and its velocity at the most contracted section, DD, is different from the velocity v_0 of the stream that passes around the baffle. For that reason, in the case of a moving baffle, the fundamental equations (1), (2), (3), and (4) have to be applied, not to the whole mass of water carried by the stream, but to that part of it only which surrounds the central column and passes around the baffle, independent of its velocity $\frac{\delta h}{\delta t}$ at the given moment. Considering, therefore, these central columns above and below the baffle merely as stems of the baffle, and signifying their outside diameters by d_3^1 and d_2^1, it becomes evident that the external appearance of all equations, when applied to the case of a moving baffle, will remain exactly the same as in the case of a stationary baffle, except that the stem diameters d_2 and d_3 have now an abstract value, depending on the velocity $\frac{\delta h}{\delta t}$ of the baffle, namely, for d_2^2 has to be taken

$$d^1{}_2^2 = \frac{d_0^2 - d_2^2}{v}\frac{\delta h}{\delta t} + d_2^2;$$

and for d_3^2 is to be taken

$$d^1{}_3^2 = \frac{d_0^2 - d_3^2}{v_1}\frac{\delta h}{\delta t} + d_3^2.$$

Consequently, the complete analytical expression of the law of hydraulic obstruction in closed streams, applying to stationary and moving obstructions alike, will be the following:

$$P - Y = 2\,\frac{(d_0^2 - d_3^2)\left(1 - \frac{1}{v_1}\frac{\delta h}{\delta t}\right)}{d_1^2 - d_3^2 - (d_0^2 - d_3^2)\frac{1}{v_1}\frac{\delta h}{\delta t}}\,(x - x_0)\,; \quad . \quad . \quad . \quad . \quad \text{(IV)}$$

which is obtained from equation (III), by substituting for d_3^2 its expression given above.

In the application of equation (IV), the computation of the total stream pressure P, due to the combined presence of baffle and upset only, ought to be made, guided by the following considerations: In applying the first part of the resulting fundamental equation (5) to the case of a moving baffle, we would have—in accordance with the foregoing—to replace all the stem diameters d_2^2 and d_3^2 by the diameters of the central water column d'^2_2 and d'^2_3, viz., $d_2^2 + \frac{d_0^2 - d_2^2}{v} \frac{\delta h}{\delta t}$ and $d_3^2 + \frac{d_0^2 - d_3^2}{v_1} \frac{\delta h}{\delta t}$; and from $P_1 - P_2$, which represents the resultant of all outside forces applied to the stems of the baffle—such as weight of baffle and attachments, spring pressure, if any; pressures upon the ends of the stems and, in the present case, also the force due to acceleration $\frac{\delta^2 h}{\delta t}$ of the baffle—we would have to substract yet the resultant of the pressures upon the baffle at its contact surfaces with the central water column, which forms now a part of the stems, and the pressure it exercises being an outside force acting opposite to the forces just mentioned. Denoting these pressures on either side of the baffle by P_1^1 and P_2^1, we have from the conditions of equilibrium of the central columns below and above the baffle:

$$P_1^1 = \frac{\pi}{4}(d'^2_2 - d_2^2)\ p + \rho\frac{\pi}{4}(d'^2_2 - d_2^2)\frac{v}{g}\left(v - \frac{\delta h}{\delta t}\right)$$
$$- \rho\frac{\pi}{4}(d'^2_2 - d_2^2)\,(H_1 + h)\,(1 + f);$$

$$P_2^1 = \frac{\pi}{4}(d'^2_3 - d_3^2)\ p_1 + \rho\frac{\pi}{4}(d'^2_3 - d_3^2)\frac{v_1}{g}\left(v_1 - \frac{\delta h}{\delta t}\right)$$
$$+ \rho\frac{\pi}{4}(d'^2_3 - d_3^2)\,(e_1 + H_2)\,(1 + f).$$

Hence, substituting for d'^2_2 and d'^2_3 their above expressions and substracting one from the other, we obtain for that resultant:

$$P_1^1 - P_2^1 = \frac{\pi}{4}\frac{d_0^2 - d_2^2}{v}\frac{\delta h}{\delta t}\Big(p - \rho\ (H_1 + h)\,(1 + f)\Big)$$
$$- \frac{\pi}{4}\frac{d_0^2 - d_3^2}{v_1}\frac{\delta h}{\delta t}$$

$$\left(p_1 + \rho\,(e_1 + H_2)\,(1 + f)\right) + \rho\,\frac{\pi}{4}\,\frac{\delta h}{\delta t}\,\frac{1}{g}\left[(d_3^2 - d_2^2)\left(v - \frac{\delta h}{\delta t}\right)\right.$$
$$\left. + (d_0^2 - d_3^2)\,(v - v_1)\right]. \quad .$$

After introducing all these changes in the first part of equation (5) and excluding p by means of equation (3), we would find that the first part of equation (5) retains all the terms it contains now, with the addition only of the following two:

$$-\rho\,\frac{\pi}{4}\,\frac{d_0^2 - d_2^2}{v}\,\frac{\delta h}{\delta t}\,Y_1$$
$$-\rho\,\frac{\pi}{4}\,\frac{\delta h}{\delta t}\,\frac{1}{g}\left[(d_0^2 - d_3^2)\,(v - v_1) + (d_3^2 - d_2^2)\left(v - \frac{\delta h}{\delta t}\right)\right],$$

divided like all other terms by

$$\rho\,\frac{\pi}{4}\left[d^2 - d_2^2 - \frac{d_0^2 - d_2^2}{v}\,\frac{\delta h}{\delta t}\right]\frac{v^2}{g}.$$

Therefore, the pressure of the central column which is to be substracted from the total outside load upon the baffle in consequence of its velocity, is:

$$P^1 = \rho\,\frac{\pi}{4}\,\frac{v^2}{g}\,\frac{\delta h}{\delta t}\,\frac{1}{v}\left[(d_0^2 - d_2^2)\;Y + (d_0^2 - d_3^2)\,\frac{v - v_1}{v}\right.$$
$$\left. + (d_3^2 - d_2^2)\,\frac{v - \frac{\delta h}{\delta t}}{v}\right] \quad . \quad . \quad (10)$$

From the foregoing the following method can be formulated for computing the pressure P which enters equation (IV) for a given baffle: From the sum of the outside forces enumerated above, substract the central column pressure P^1 as per equation (10), and also the constant terms as given in first part of equation (5) and the constant terms of equation (III); the obtained result, divided by the initial quantity of motion of that mass of the stream that passes around the baffle, viz.:

$$\rho\,\frac{\pi}{4}\left[d^2 - d_2^2 - \frac{d_0^2 - d_2}{v}\,\frac{\delta h}{\delta t}\right]\frac{v^2}{g}$$

which constitutes our accepted unit of pressure, represents the resultant pressure of the stream due to combined presence of

baffle and upset only, and nothing else, and denoted by P in equation (IV).

With regard to the possible value of the velocity of the baffle $\frac{\delta h}{\delta t}$, the only limiting condition apparently is, that the deformation of the stream should preserve the same character as with a stationary baffle. Analytically that would mean that P should be greater than Y and x greater than x_0 in equation (IV).

This will be the case as long as the velocity of the baffle is less than the final velocity of the stream; that is,

$$\frac{\delta h}{\delta t} < v_1;$$

and still more so when $\frac{\delta h}{\delta t}$ becomes negative; that is, the baffle moving against the stream. As soon as the baffle moves in the direction of the stream with a velocity greater than the final velocity of the stream v_1, then part of the stream will be forced back with probable distortion of the stream deformation, and the application of equation (IV) would become uncertain.

As in practice immersed bodies are usually in a state of motion or vibration when acted upon by a stream, as in cases of check valves and pump valves, the introduction of the momentary velocity $\frac{\delta h}{\delta t}$ of the obstruction becomes an evident advantage, making the law applicable to all phenomena of obstructions within closed streams, without exception.

DCCLXII.*

AUXILIARY ENGINES AND TRANSMISSION OF POWER ON NAVAL VESSELS.

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(Member of the Society.)

THE subject of this paper may lead the writer into some discussion with the builders of special types of auxiliary machinery in use on naval vessels, as did a paper read before Section G of the Engineering Congress held in connection with the World's Columbian Exposition. This, however, is not the object of this paper. Our desire is to present the subject as a whole, as it appears to the engineer who has to deal with the machinery required for the many purposes where power other than manual must be provided, in its completed form on board ship, and as each part and the function it performs is related to the general result aimed at.

Unfortunately, on government vessels, the work which has to be done by machinery is divided up and placed under the cognizance of various bureaus, each having a decided preference for some particular mode of transmitting power, which might really be the best for the particular work of that bureau, but may not be applicable at all to the class of work under the cognizance of another bureau, the result being that in one ship we are very likely to find three different methods of transmitting power in use, and no one in charge master of any one method.

In mentioning three methods of transmitting power in use on our naval vessels we exclude steam, that being the original form in which the power at present is generated, and therefore can be distributed without any reconverting mechanism.

Electric power is generated for lighting purposes, for controlling search lights, operating small fans for special purposes, and for signal purposes. In quite a large number of vessels electric power is used to operate ammunition hoists, and in one or two

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recent cases the lighter turrets have been operated by electric motors. In some vessels now building a further extension of electric transmission of power is being made to include the large turrets and all the gun-mount movements of the large guns. So that we now have the Ordnance Bureau fairly committed to this method of transmission.

In some of our ships the distribution of power is divided between electric and hydraulic transmission, the main battery being operated, including the turrets, by hydraulic power, while the ammunition for all secondary guns is served by electric hoists; while in others, the battleship *Oregon* being a good example, the main turrets and their guns are not only entirely operated by hydraulic motors, but all ammunition hoists throughout the ship, battle-doors, etc., are worked from the same source of power. This vessel is also fitted with hydraulic steering gear.

Compressed air has been used to some extent as a means of transmitting power on some of our vessels, and is provided on all vessels carrying torpedoes for charging these intricate self-propelling projectiles.

Colonel Soliani, Chief Engineer of the Italian Navy Department, has strongly advocated compressed air as a means of transmitting power for all purposes on warships, except for operating large turrets, for which he prefers hydraulic power.

There are also those who advocate the use of steam direct on all auxiliaries, including the working of all turrets, ammunition hoists, and even the manipulation of the guns. The Bureau of Steam Engineering naturally favors this direct application of steam as the most economical method, in power used, in weight, and in efficiency.

In the present state of the art of transmitting power to all parts of a modern warship it is not possible to compare one method with another as a whole, and from actual experience, there being no one ship with a complete system of transmission from a central generating station of one type to compare with another ship having an equally complete system from a central generating station of another type.

In the comparisons to be made and the conclusions arrived at in this paper, the writer must, therefore, depend upon his own observation of the working of mixed systems, and his general experience in regard to each system of transmission.

Since the presentation of the paper referred to at the International Congress of Engineers, experience on this subject has broadened somewhat, and the power of fashion has been felt in engineering, as well as in social questions. Young men are being trained into a fitness for understanding and caring for one form of power transmission in preference to others, which, though older, are not so much before the public.

Engineering methods in the navy, like the engineers themselves, appear to be retired on account of age, that the younger methods may have a chance. So that we find that naval officers beginning their experience are eager to become acquainted with the new and fashionable methods of power generation and transmission, while they do not care to make the acquaintance of the older methods. So the old is neglected and receives no benefit from the better education of the young officers, while the new and more attractive method gets all the benefit of being cared for and nursed into efficiency by the brightest young men in the service. Who to-day would prefer to be wet nurses to a hydraulic pump to producing potential energy from an electric generating set?

Still, there must be more than outward attractiveness in any method of power transmission to secure its adoption and retention on board a warship where reliability and efficiency must ultimately decide as to what can remain and what must be replaced by something better.

In our investigation of the various methods in use we will consider not only what they at present are, but what they might be if all that is known in regard to them were utilized in the installation, and we will assume that, *first*, all operations on a warship requiring power can, with properly designed mechanism, be performed by steam direct from the boilers.

Second, all operations on a warship requiring power can, with properly designed mechanism, be performed by water under a high pressure imparted to it by steam-operated pumps.

Third, all operations on a warship requiring power can, with properly designed machinery, be performed by air under pressure imparted to it by steam-operated air compressors.

Fourth, all operations on a warship requiring power can, with properly designed machinery, be performed by electric motors, using a current generated in a central station by steam-driven generators.

The idea that each of these four methods was suited to some functions and not to others is the reason why mixed systems prevail on all of our ships, and how far our assumption that this is not the case can be maintained will be the subject of our present inquiry.

Keeping to the order which we have indicated, the application of steam direct to all purposes first claims our consideration.

In all of our war vessels steam is used direct on a large number of the auxiliary machines throughout the vessel, and in all of them, except those fitted with hydraulic steering gear, the steam is carried from end to end of the ship, the steam windlass being at the one end and the steam steering gear at the other, requiring two lines of steam-heated pipe for the whole length of the vessel. Between these points, both on upper and lower decks, machines are operated by steam on all our ships. On the upper decks there are steam winches, steam windlass, steam boat cranes, and steam ash hoists; and on lower decks, outside the engine and boiler compartments, there are steam ventilating fans, steam air compressors for torpedo-charging, steam steering gear, and in some of the vessels steam turning gear for turrets and steam ammunition hoists.

We see no mechanical difficulty in the way of steam being applied direct to all auxiliary machinery. Its elasticity, it is claimed, renders it difficult to train heavy turrets by this agent, and we are satisfied that, to have full control of accurate movements of such heavy masses by steam, some very reliable controlling device must be introduced, and for this purpose we have been introducing into recent designs a continuous and automatic hydraulic control which should make all movements of a steam-operated turret as accurate as those operated by hydraulic motors.

Compressed air and electricity need to be controlled through an inelastic medium to the same extent as steam does, when applied to such work as moving large turrets.

Granted that steam is capable of operating direct every class of auxiliary machine on a warship, and seeing that it is on hand at all times and always ready, how comes it that on all of our ships this steam is converted into some other form of energy and in this new form is applied to certain operations that it might just as well be applied to direct?

Those who claim that steam should be converted into some

other form of energy and distributed to the various machines base their claim on three points of advantage—safety, economy, and comfort. The presence of steam pipes in all compartments of a war vessel must be considered in connection with the business in which the vessel is to be engaged, and that is to fight. In action these pipes would all have to be open at least from the forward turret to the steering engines in the stern, and are more or less subject to damage. It would be difficult to overestimate the loss which might result from a broken steam pipe in any compartment under the main deck of a war vessel in action. Such an accident might not only involve the loss of all men in such a compartment, but the total disablement of the ship as a fighting machine.

It is difficult to determine the relative economy of steam as applied direct throughout a ship and as applied through some other agent. The great source of loss is through condensation. Nearly all the machines which use steam in naval vessels, outside of those directly connected with the propelling of the vessel, do so intermittently, and masses of metal must be heated up every time a movement is made. There is no doubt that a large portion of the steam used goes to renew lost heat in this way, and is condensed without doing any useful work; besides this source of waste, the steam engines used for auxiliary work are of necessity of the most wasteful character. As a rule they are reversing, the reversing gear usually consisting of a reversing valve operated through some form of floating lever. The waste of steam in this class of engines is enormous, and we hardly think that on an average a horse-power is obtained for each one hundred pounds of steam used. The combined waste from condensation and wasteful motors must result in a large expenditure of fuel in proportion to the work done, and in our opinion makes the direct application of steam to auxiliary machinery on warships the least economical of the methods in use.

The objection to the direct use of steam on account of the discomfort caused by heat in places difficult to ventilate efficiently is, perhaps, the most serious objection made to this method of power distribution. Steam and exhaust pipes running to the various machines must be carried as a matter of safety below the protective deck line, and for the same reason all engines requiring to be operated in time of action are also placed below that deck, where ventilation is very difficult, even

where there are no engines; but with steam engines in or under handling rooms, and in recesses formed in ammunition passages, and with battle hatches closed, it is difficult to see how men can possibly carry on the work of tending such engines, serve ammunition hoists, and perform all the duties required of the under-deck force in time of battle. Physical endurance has always been a prime factor in action, and no method of distributing power should be adopted in a warship which renders it impossible for every man to do his duty in the time of trial.

We may now consider our second assumption, that all operations on a warship requiring power can, with properly designed machinery, be performed by water under a high pressure imparted to it by steam-operated pumps.

In our paper already referred to, read before the Division of Marine Engineering and Naval Architecture of the International Engineering Congress, the question of hydraulic transmission of power on warships was very fully discussed, and the general proposition of a central hydraulic station within the enclosure containing the main engines and boilers, where the water would be placed under pressure by pumps operated by the most economical type of steam engine under the immediate supervision of the engineer officers of the vessel, and its manner of distribution, was fully set forth.

During the four years which have elapsed since that paper was written, and in view of whatever experience has been gained on the subject during that time, we are still of the opinion then expressed, that most of the work required of auxiliary machines on warships can be better done by hydraulic than any other means of transmission; and if so, how about the qualities we considered in connection with steam applied direct —safety, economy, and comfort?

In considering the question of safety we must not only take into account dangers resulting from accident to the means of transmission, but the danger which might result to the vessel as a whole if this means of transmission was not as reliable in its action as any other means of transmitting power.

The danger we pointed out from the possibility of damage to a steam pipe where steam was used direct, does not exist in connection with hydraulic transmission; the result being simply cutting out of service the machine to which such a pipe

leads. As to reliability, our experience proves that after the first difficulties are overcome there is no form of power transmission which can be depended upon with more confidence than hydraulic. At first it needs a wet nurse ; particles of rust, scale, chips, etc., in the many connections of such a complicated system of distribution as would be required on a warship, coupled with defective material in parts, try the patience of the nurse; but once these microbes are out of the hydraulic system, a long and useful life is pretty sure to follow.

Partial hydraulic systems are now on warships under the care of officers who have had no opportunity to become expert in hydraulic work, and who in many cases do not believe in its application, and yet the record of failure at any time to perform the functions required is a remarkably clean one ; so, as regards safety, either to the system itself, the vessel as a whole in which it is installed, or the life of those connected with its operation, the hydraulic system of transmission is certainly superior to any method of direct steam application.

Granting that this system is eminently safe, is it an economical method of distribution?

It has generally been allowed even by those who are most strongly in favor of its adoption that, owing to the conditions which govern the operation of most auxiliaries on board warships, economy must be sacrificed when a hydraulic system is adopted. Hydraulic motors for any of the varied purposes requiring power on warships must be designed large enough to meet the maximum requirements of the service, and if these motors are of the piston or plunger type, the regular form at present in use, the maximum amount of power will always be used, although the minimum work only is required.

If, instead of using a motor having cylinders with moving pistons or rams, utilizing the pressure to obtain power, and measuring out a given quantity of water for each movement, irrespective of the work to be done, the pressure water was applied to a properly designed wheel of the tangential type, an efficiency averaging about 70 per cent. could be obtained with a great variation in the load, and thus one source of waste with this system would be avoided.

The direct ram would be still retained for certain purposes where the precision of movement is of the first importance, such as in steering gears and gun-training movements.

The American mania for direct-acting steam pumps to generate power for such an installation is the most fatal obstacle to be encountered in any effort to reach reasonable economy in a hydraulic system of power transmission on board our warships. In some of the battleships now building it is proposed to install, for the generation of hydraulic power, say six duplex hydraulic pumps of 400 gallons capacity each per minute, at 600 pounds pressure per square inch; this requires twelve steam cylinders, 22 inches diameter, and say 24 inches stroke, being with pump friction about 950 horse-power. This will require with the type of pump proposed not less than 95,000 pounds of steam per hour, and this certainly would give on the main engines 5,000 horse-power. Half the total boiler power of the ship with forced draught would be absorbed by such a pump installation, if working at its full capacity.

This is the main reason why hydraulic power is condemned, on account of the fuel required for the regular daily practice with the mechanism now operated by water on those ships so fitted.

There is no reason why hydraulic power should not be generated by as economical steam engines as any other form of energy, and with economy in its production, which can be reached by means now at our disposal, and applying the power thus generated through motors best adapted for an economical application of this power, keeping in view functional economy as well as quantitative economy. There is no reason which we can discover why a hydraulic system of power distribution for all purposes requiring power should not be more economical than steam applied direct, provided ordinary steam pumps are avoided in the generating department, and something else than water meters used as motors.

As to comfort: The presence of hydraulic pipes in any of the living spaces, store-rooms, or magazines in no way affects the temperature or ventilation of such spaces. Branch pipes in very few cases need exceed 1½ inches in diameter. Any leakage is easily discovered and can do no damage. The working of all water motors can be accomplished without noise, and, there being little or no change in the temperature, all joints when once tight are likely to remain so, and this is the one great comfort always attending a well-designed and carefully installed hydraulic system of transmission.

Our third assumption, that all operations on a warship requiring power can, with properly designed machinery, be performed by air under pressure imparted to it by steam-operated air compressors, may now be considered.

This means of transmitting power in warships has been advocated at different times, and by men well qualified to give an opinion, and who have had opportunities to test partially its merits as against other methods. We have mentioned in this connection Colonel Soliani, Chief Engineer of the Italian Navy Department, who, in comparing the various methods now in use on board war vessels for transmitting power consisting of steam direct, hydraulic, compressed air, and electricity, sums up the advantages and disadvantages of these different methods by giving the preference to compressed air for all purposes except handling big guns and turrets, for which he would use hydraulic power.

As our aim would be to have on any given ship but one method of power transmission, we would not make any exceptions in regard to the operation of large guns or turrets.

Steam and electricity, when applied to handling large guns and turrets, have the same objectionable features as compressed air, combined with other objections peculiar to themselves. The objection to compressed air in this connection is its elasticity, preventing accurate movements being made with certainty. This can be overcome by the introduction of a continuous and automatic hydraulic control as mentioned in connection with the use of steam direct, and which we will more fully describe in connection with the application of electricity to the manipulation of big guns and turret mounts.

Granting, then, our assumption of the possibility of a compressed-air system of power on warships being made serviceable for all auxiliary purposes, we may now consider the qualities of safety, economy, and comfort in their relation to this system.

Perhaps no form of power transmission has all the elements of safety in the same degree as compressed air. A leak in the transmission pipes improves the ventilation and adds to the comfort of those working in that compartment. The pressure carried, of, say, six atmospheres, makes all kinds of connections simple and easily cared for. Double bottoms and difficult places of access can be purified and ventilated by a small jet from the distributing pipes. Water may be excluded from any

damaged compartment which can be made air-tight down to the level of the opening that admits the water. The writer floated one ship, the *Jessie Osborn*, which was stranded on the rocks north of San Francisco Bay, when great sections of the bottom were entirely gone, by stiffening and caulking the hold deck, and by means of an air compressor forcing air under that deck, thereby forcing the water out through the open bottom, lifting the ship up to almost her light draught.

Any compartment in a warship using a compressed-air system of power transmission can be promptly cleared of water by this means, the extent of the aperture by which the water enters being of no consequence. This being kept in view in designing and building the vessel, would render this method of transmitting power one of the greatest elements of safety and give an immense added value to the under-water compartments; so that, should one or more compartments be damaged by either striking a rock or being struck by a torpedo, such compartment would simply be put out of use, but by keeping it charged with air to a pressure equal to the draught of water of the vessel, its buoyancy would not be impaired if the damage was in the bottom, as it most likely would be.

We have mentioned this advantage in the use of compressed air because it is the only one of these three systems of power transmission which can be so used in connection with the general safety of the vessel.

In the matter of economy, both in generating and in distribution, the compressed air, if proper methods are adopted, should be at least equal to any of the other systems which have been tried. The compressors used should be of the most modern type—triple expansion of steam and triple compression of air, and with storage enough to meet sudden calls.

No system is so well adapted to the installation of power being made to equal the average required instead of the maximum. Soliani mentions the success obtained by Professor Riedler in compressing air in two stages. This method of compressing has during the past few years become almost universal where any degree of economy is aimed at, and, while it has no direct bearing on the subject of generating power for transmission through a warship, yet, in justice to ourselves, we desire to state that in 1876 we designed an air compressor which was built for use at the Crown Point Mine, Virginia City, Nevada, in which the air

was compressed in two stages, and the steam expanded in two stages; that is, both the steam and air ends of the machine were compound. We published a plan and description of this air compressor in 1877 in a book on *Hoisting and Pumping Machinery*, from which we quote the following:

"The compressor (Fig. 53) consists of two fixed rams, one of 26 inches diameter, secured to the bed plate, and another of 12 inches diameter, secured to the entablature; between these rams and upon them, is a sliding cylinder, water-jacketed all over. Be-

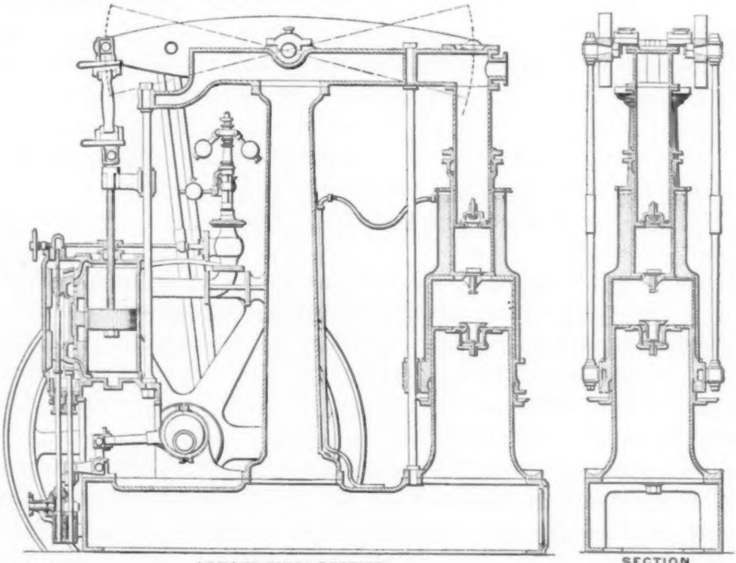

FIG. 53.

tween the large and small end of the cyclinder is a valve opening upwards, and on the head of the large ram and the butt of the small ram are valves opening upward.

"Suppose the sliding cylinder on the bottom centre and the steam cylinder piston at the top, steam being admitted on the piston; the sliding cylinder will rise and take air through the valve in the head of the large ram until it reaches the top centre. The space above the large ram will then have air at the atmospheric pressure. Steam then being admitted to the other side of the piston, the sliding cylinder descends, the valve in the head of the large ram closes, and the valve between the large

and small cylinders opens, and the air during this stroke is compressed into the small cylinder. During the next up-stroke this compressed air is forced through the valve in the bottom of the small ram into the receiver at the same time the air is being taken again through the valve in the head of the large ram.

"The work of compression is thus extended over two strokes, or a complete revolution of the engine, and more time is obtained for abstracting the heat generated in the operation. The valves, which are only three in number, all lift upward, and need no device to seat them. All of the valves remain open during the greater part of the stroke, and have not such a quick action as when the compression is done in one cylinder with the delivery valves open for a small fraction of a second at the end of the stroke.

"We also consider the ram better than the piston, as any leakage is at once seen and readily stopped.

"The steam cylinder for this compressor is also fitted with a variable cut-off.

"In large machines of this class, we would make them double, using two compressor cylinders moving in opposite directions, and a compound condensing engine where water could be had.

"Compressed air is being used to such an extent in the mines that anything which will tend to cheapen the compressing will have its effect on the fuel bills."

This last sentence which we quote appears to have been an unfortunate statement, for, while the compressor referred to was being built for the Crown Point Mine, a change took place in those controlling the mine whereby the parties which sold wood for fuel to all the mines came into power, and being afraid that the statement made about saving fuel might be true, they concluded that it would be better for their interests to accept the 250 horse-power new compressor, and put it in some safe place out of sight, where it could not interfere with the consumption of cord wood, and there it remains to this day.

A small compressor for charging the air chambers of the hydraulic pumping plant at the combination shaft, Virginia City, was made at about the same time, which delivered air compressed to 2,000 pounds per square inch, working perfectly. Fig. 53 is a photograph taken from the illustrations in the book referred to, and to which the quotation refers. Since then this method of compressing, with many variations in the mechanism

by which it is accomplished, has been accepted as the most economical method of compressing air for the transmission of power.

With an air receiver of considerable size and two compressors, one small to supply power to operate steering gear, ventilation, and other functions constantly in use, the main compressor need only be operated when the crew are at quarters, and all the fighting machines of the ship are being moved, or in action.

The lubrication of air motors at the low temperature reached in working them expansively is beginning to be better understood, and difficulties due to the formation of ice in exhaust passages where the air carries moisture can also be obviated.

In 1876 we operated compound air motors with considerable expansion, and to avoid the difficulties mentioned, had recourse to devices that have been invented several times since.

In explanation we quote, from the book already referred to, the following in reference to compound pumps operated by air:

"Afraid that the compressed air, holding, as it always does, some water in suspension, by being expanded into four times the volume might, by the loss of temperature, cause the formation of ice in the passages leading to and from the low-pressure cylinder, we have taken advantage of the fact that water in most of our mines is warm, and encased the cylinder in the pump discharge, or column, or, in other words, we have water-jacketed the low-pressure cylinder and nozzles. Should this pump be used for steam, the discharge would then pass on without going into the jacket."

The above quotation shows that over twenty years ago we had been working on problems that have since been solved on lines almost parallel to those on which we were then working.

With the most economical steam engine, operating the most economical compressor, and the compressed air converted into useful work through economical air motors, this system of power transmission on warships should meet every requirement on the score of economy.

As to comfort, we have already pointed out some of its advantages. No return pipes are required, as in all other systems, electricity not excepted. The liberated air from motors will ventilate and cool the spaces in which they operate, and these spaces are usually the most difficult to ventilate.

In the hydraulic system all losses by leakage must be made up by fresh water manufactured on board, whereas by this system the more loss the better it feels where the loss has occurred, and the feeling of absolute safety in case of any break in the transmission pipes must add to the efficiency of the men whose duty requires them to work beside the motors and the pipes which supply the power to them.

All the machinery required in such a system of transmission is of a character now well understood by the engineer officers on our warships, and the difficulties attendant on operating mechanism not understood by the operator are avoided.

Our fourth assumption, that all operations on a warship requiring power can, with properly designed machinery, be performed by electric motors, using a current generated in a central station by steam-driven generators, now remains to be considered.

The advocates of this system have a foundation for their method of power transmission which those who favor any of the other methods do not possess, in the fact that all modern warships have a certain amount of power converted into electric energy and distributed throughout the ship for lighting purposes.

While there is no difficulty in generating electricity by the use of water or air motors, there is the waste of converting the steam into one form of energy and converting that again into another form of energy. To justify such a course it would be necessary to prove that water or air as a transmitting agent possessed, for all purposes but lighting, a great advantage over any known method of electric transmission.

This, in the present condition of the art of transmitting power by generated electricity, cannot be maintained. We must therefore concede that the electric method has the advantage of undisputed possession of the field for at least one part of the work to be done.

Another advantage which electricity possesses, here as everywhere else in the field of applied mechanics, is that young engineers are educated into the knowledge of how best to generate and apply this agent in a manner which has never been thought necessary in regard to other forms of stored-up energy, and, it being the fashionable agent for power distribution throughout the engineering world, its development is one of the modern wonders of engineering.

An electric installation for all power purposes on board warships will, on account of the education of the engineers or other officers in charge, receive more intelligent care and more skilful application than any of the other methods which we have considered.

While this advantage is not inherent in the system itself, it is of the utmost practical importance in its successful application.

The transmitting wires of the electric system possess a flexibility which cannot be claimed for the pipes of the other systems. This is an important advantage in the crowded compartments of a warship.

As to safety, economy, and comfort, we may now consider these in comparison with other systems.

In regard to safety: We might safely take it for granted that whatever disturbance would fracture the pipes of an air or water system would part the wires of an electric system. In that case the danger to life and also to the ship would be far greater with the electric system than with the others, steam excepted. Automatic safeties could be applied to almost any conceivable extent against such accidents, yet, where safety devices are needed, the system cannot be so safe as where no safety devices are needed.

There is also a growing fear amongst marine engineers that certain materials are rapidly destroyed by electric action, caused by the hull of the vessel becoming magnetized in some way, the nature of which is not yet fully understood. It is claimed that vessels fitted with electric generators develop rapid deterioration in all sea-water pipe connections. Whether sufficient reliable data have been collected, either to establish or refute this claim, is, we think, doubtful. It is a question which, we think, ought to be most fully investigated. At present it is simply a matter of conjecture, and to marine engineers a matter of considerable uneasiness.

As to economy: The electric generating plant has been developed both electrically and commercially into a high degree of efficiency. Direct-operated generators are now driven by engines of the very highest developed type. These engines are so perfectly controlled by automatic valve governors that full load or no load may be the condition without apparent change in the working of the steam motor.

The generators may be so divided into units as to meet the

conditions of work at any time without much of the steam-engine power running without load. Lighting and power can be taken from the same installation, thus effecting a saving in the labor of attendance. There is no doubt that the economy of generating the power electrically will be better than with either water or air, owing to the high speed of the engines and the small amount of loss in the generating mechanism.

In regard to the distribution, the losses, by careful installation, can be reduced until they shall at least not exceed the losses of friction in either air or water pipes of the other methods. Careful designing may also reduce the losses in converting the electric energy into mechanical movements, so that the economy of this part of the system may be better than in either air or water motors.

All this class of work has been so perfected that every function requiring power on a warship can be performed by electric motors without involving the use of anything except well-known and tried mechanism.

It is not our purpose in this paper to give the details of operating motors for windlass, winches, capstan, boat cranes, steering gears, ventilating fans, ammunition hoists, gun-mount manipulating gears, etc., as none of these operations involve the use of any electric device which is not now well known.

In operating large turrets where the mass to be moved and controlled is very great, and on a continually shifting plane, we believe that some controlling mechanism of a special character will be required to insure successful and accurate movements of such masses on a moving platform.

For this purpose we have introduced a hydraulic control device, consisting of two hydraulic cylinders (Fig. 54), double-acting, their pistons operated by a double-throw crank-shaft, which forms one of the transmitting shafts between the electric motor and the fixed rack under the turret. These cylinders are charged with water or oil. Motion of the turret revolves the crank-shaft and moves the pistons in the cylinders. The fluid must pass from one side to the other to permit of such motion. This it does through passages connecting the ends of the cylinders. There are two such passages, one being controlled by a valve operated from the sighting station, and is opened as the current is turned on to the motor. The other is controlled by a spring-loaded valve and gives a fixed maximum control. This is neces-

sary, as, if the hand control were closed too quickly, the momentum of the moving mass would break the mechanism.

We also propose to avoid great waste of current in starting this heavy mass, by using a small high-speed motor to effect the first movement, or for small movements of the turret. If it is necessary to throw the current into the main motor, a certain

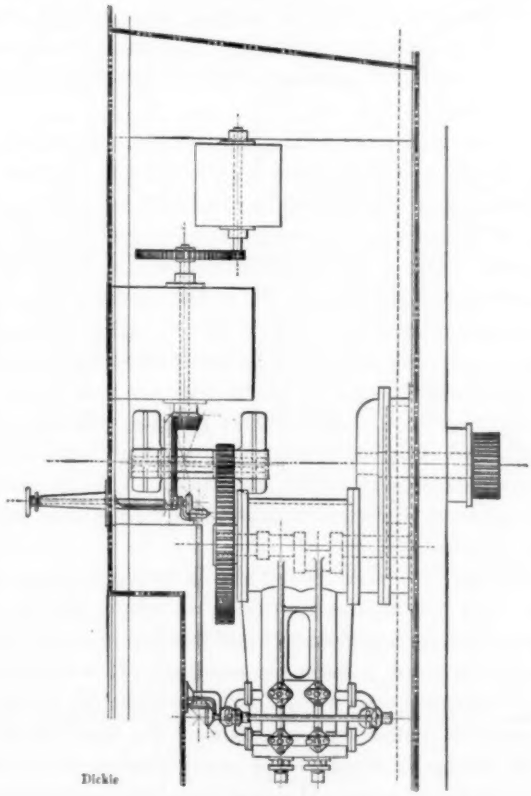

FIG. 54.

speed is reached before that is done; consequently the shock and waste of current are avoided, as the main motor would only be used when a high speed of train was required, and then only after the inertia of the mass has been overcome. In making these movements, the small motor is allowed to reach its load when the current is switched into the main motor. The current in the small motor also excites a solenoid, which by proper

mechanism couples the shaft of the small motor with the pinion that, through a gear of, say, 10 to 1, works the shaft of the main motor; but when the current is turned into the main motor, the solenoid is cut out and the clutch withdrawn, thus leaving the small motor at rest.

Fig. 55 is a sketch of a small portion of a turret, showing the motors, gearing, and hydraulic control. The actual economy which would result from such a method of operation could only be determined by actual experience. But we feel confident that it would prove to be in advance of the economy possible with either air or water.

One other reason for expecting a good economical result from a complete electrical power transmission lies in the fact, already mentioned, that this system would receive more skilful attention on the part of the officers in charge than any of the other methods mentioned. The whole installation would be more attractive to the educated engineer. It is the fashionable power of the day, and young men are more eager to give their attention to this than to any other form of generated energy; and if any system is the thing desired by those who are to have the operating of it, that system will give better results, will be more carefully nursed, and will be studied in all its details, with the object of improving every result obtained. This is natural, and must be considered in connection with any proposed advance in engineering methods.

Some time ago we were fitting the Howden system of forced combustion to a vessel, the engineer of which did not believe in its merits; but he was honest, and assured us that he would do nothing to prevent it being a success. It was necessary to find another engineer who would do everything he could to help make it a success before success came. So the fact of electric transmission being desired by so many engineers is one point in its favor which will secure the care that means economy, apart altogether from the inherent qualities of the system itself as compared with others.

In regard to comfort it cannot be claimed that an electric system of power transmission on a warship, like a compressed-air system, can be made the means of increasing the comfort of living on board. On this point it should rank with a hydraulic system. The facility with which electric energy can be converted into rapid rotary motion makes ventilation, wherever that

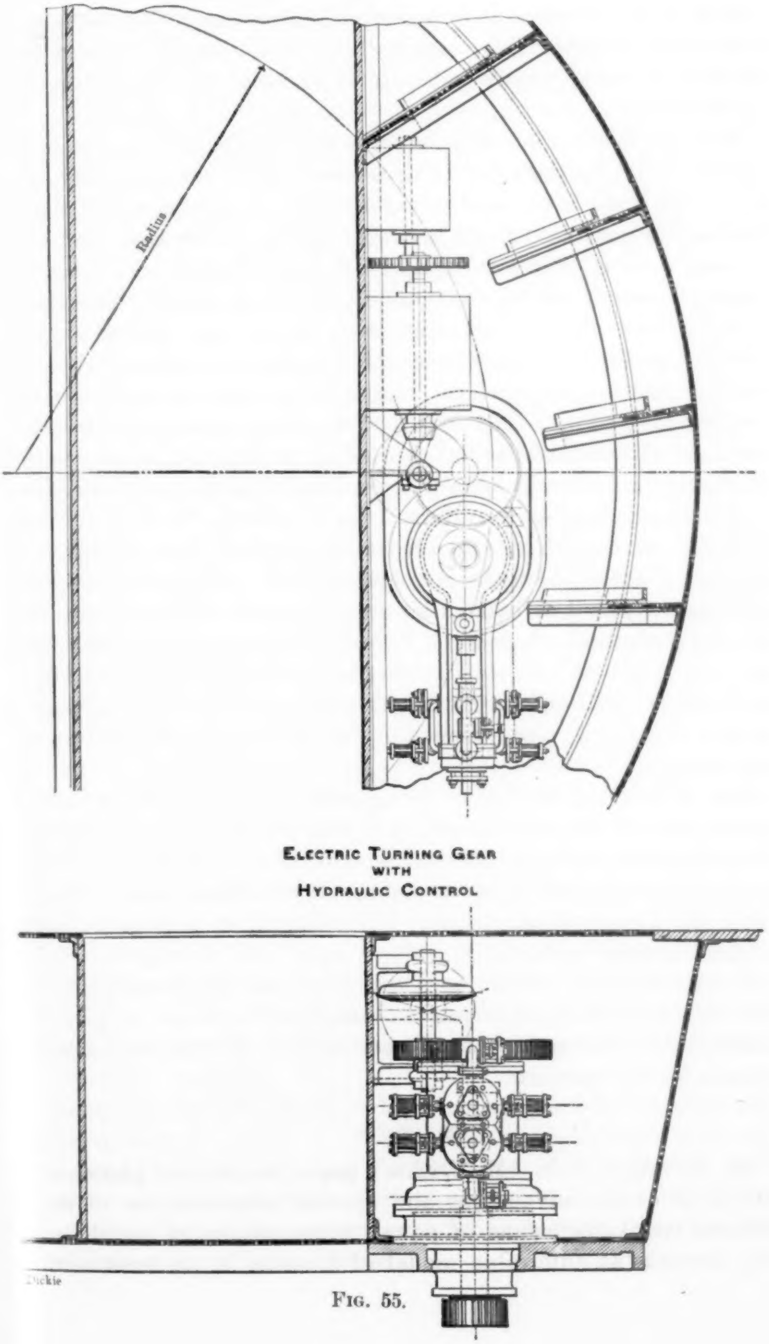

Fig. 55.

power is distributed, a very simple matter, and electric fans, both fixed and portable, especially where little or no heat is generated, would supply pure air to all parts needing artificial ventilation.

This paper does not aim to show the superiority of any one system over another, the comparisons made being simply to show that there is no mechanical difficulty in operating all auxiliaries by any one of the systems herein mentioned, and to express a hope that our government would either adopt some one system and carry it out completely, developing that system to its utmost efficiency, or else take one or two similar ships and fit them with power-transmission systems completely representing different agents—say, one electric, one hydraulic, and one compressed air. Let each be placed for three years in the hands of officers heartily in favor of the system in use on their own ship, and thereby obtain a practical demonstration of the very best points in each system.

While we have hitherto advocated with all the ability we possess a complete hydraulic system, our experience in the practical working of hydraulics on shipboard has not been of the most pleasant character. Officers are required to care for and get the best out of a hydraulic system, while personally they would rather sit up all night with an electric plant than spend a moment more than the law requires with a water motor.

The future hopes of the young officer are centred in electricity, and he devotes himself to it with a will; and so long as that condition prevails, the electric method of transmission will have the best chance to succeed, because with that it has a flexibility and a general adaptability which the other systems do not in themselves possess.

If what we have written here will draw into the discussion of the subject the best experience in each of the systems of power transmission on warships, it will accomplish all that its author expects for the present.

DISCUSSION.

Mr. Horace B. Gale.—Mr. Dickie's paper, in its brief and clear statement of the advantages and special adaptabilities of the different available means of power transmission on naval vessels, presents an admirable model of fairness in its treatment,

and cannot fail to be interesting and suggestive to mechanical engineers in every branch of the profession. Our attention is very properly drawn to the fact, that the efficiency to be considered in a system of power transmission for a warship is the fighting efficiency, and in the selection of a system the greatest weight should be given to considerations of its reliability and safety in action.

No engineer who has ever threaded his way through the maze of machinery constituting the interior "works" of a modern war vessel will disagree with the author's desire to see a single comprehensive system of power transmission substituted for the complex variety of systems generally comprised in present equipments; and that this desideratum can be attained in a practical manner is made clear in the paper, though there are some places where I wish the author's statements were less brief. For example, he says: "In regard to safety: We might safely take it for granted that whatever disturbance would fracture the pipes of an air or water system would part the wires of an electric system. In that case the danger to life and also to the ship would be far greater with the electric system than with the others, steam excepted."

It is not apparent to me why this is so.

In a pipe system the breakage of a pipe would result in an immediate escape of a portion of the confined fluid, which might so reduce the pressure in the system as to disable temporarily the apparatus near the break. A break in an electric wire, however, would not usually have any similar effect, nor cause any reduction of pressure on the system. A broken wire, also, can be more easily and quickly repaired than can a broken pipe.

The danger of fire from electric-power wires would be no greater than that from lighting wires, which necessarily run to every part of the ship; indeed, it would be rather less, as the power wires can be more thoroughly kept out of contact with combustible material.

Moreover, the flexibility and cheapness of wire connections make it easy to install a system of multiple circuits, suitably protected by fuses, such that the breakage of any wire or pair of wires will not only not reduce the pressure in the neighborhood of the break, but cannot, even for an instant, interrupt the service in any part of the vessel.

Considering, therefore, the transmitting apparatus alone, it appears to me, as I believe it will appear to other electrical engineers, that a wire system can be designed so as to be much safer and more reliable under fighting conditions than the best pipe system can be, whether the fluid conveyed be steam, water, or air.

Mr. H. H. Suplee.—While Mr. Dickie does not especially advocate any form, he makes some remarks on page 246 about the entire safety of compressed air which I think may need a little modification. That is, that there have been recently a number of serious explosions of air compressors in various places. They are not explosions of compressed air, but practically explosions of gas. In other words, the higher pressures which are being used with compressed air cause higher temperatures, and those temperatures volatilize and carbonize lubricating oil, and a mixture is made not dissimilar to that in the explosion chamber of a petroleum engine. Some of the modern petroleum engines have been made so that they require no ignition except that of the heat generated by the compression. An explosion took place a year ago in Germany, at Dortmund, where a part of the compressor was blown entirely over a tall building, and two men were killed and serious damage done. The valve chambers were not water-jacketed as the rest of the cylinders had been. An examination of similar machines showed that they produced a high enough temperature to explode a mixture of air and gas. Such explosions might be very serious on shipboard. So it is not entirely fair to claim that the air-compression system is absolutely safe.

DCCLXIII.*

TEST OF CENTRIFUGAL PUMPS AND CALIBRATION OF WEIR AT THE BRIDGEPORT PUMPING STATION, CHICAGO, ILL.

BY R. C. CARPENTER, ITHACA, N. Y.

(Member of the Society.)

THE test described in the following paper was conducted by Messrs. R. W. Hunt & Co. for the city of Chicago at the request of Samuel G. Artingstall, City Engineer, in July, 1893, to determine the efficiency and capacity of the various pumps at the Sewerage Pumping Station at Bridgeport, Chicago. The writer, in conjunction with Mr. John C. McMynn, of Robert W. Hunt & Co., acted as engineer of tests, and together with Mr. John Ericson, Assistant City Engineer, Mr. D. W. Church, and a corps of engineers, represented the city of Chicago. The contractor for the "Undulating" pumps was represented by Mr. Bernard Fiend and Mr. Davis.

Description of Plant.—The plant was constructed for the purpose of delivering a sufficient amount of water from Chicago River into the Illinois and Michigan Canal to induce a current to flow from Lake Michigan toward the pumping station and into the Illinois and Michigan Canal, so as to prevent the discharge of sewerage into Lake Michigan. The Illinois and Michigan Canal connects Lake Michigan with a tributary of the Mississippi and descends to the level of Chicago River by a lock which has a lift of about eight feet in times of low water and three to five feet in times of high water. The pumps at the pumping station are required to raise the water from Chicago River sufficiently high to be discharged into the canal. The accompanying map (Fig. 56) shows the point of junction of the Illinois and Michigan Canal and Chicago River. It also shows the position of the Bridgeport pumping station, which is

* Presented at the New York meeting (November, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

located on a new canal, or feeder, of which two sections are shown at *A.B.* and *C.D.* respectively; this latter discharges into the Illinois and Michigan Canal about 400 feet from the lock. The Chicago River is virtually an open and navigable sewer and the material pumped at the Bridgeport station is sewage diluted by the inflow of water from Lake Michigan. This matter contains considerable floating débris of an organic nature, is very darkly colored, and of an unsavory odor. Gas of a sulphurous nature is emitted, sufficient in amount to blacken silver watches, when carried in the pocket of the observers working at the station-house, in a few hours. Sounding rods painted with white lead were turned instantly and permanently black

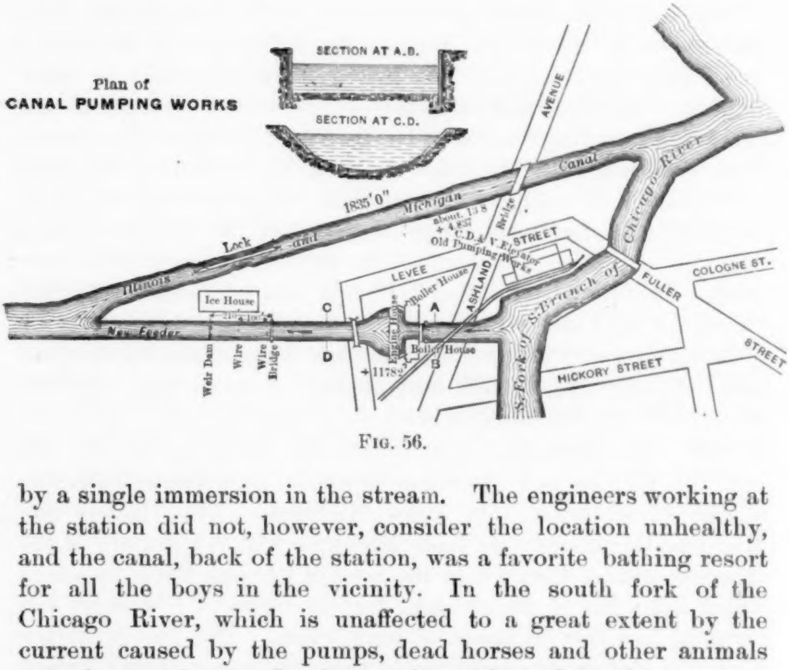

FIG. 56.

by a single immersion in the stream. The engineers working at the station did not, however, consider the location unhealthy, and the canal, back of the station, was a favorite bathing resort for all the boys in the vicinity. In the south fork of the Chicago River, which is unaffected to a great extent by the current caused by the pumps, dead horses and other animals were frequently seen floating on the surface of the river.

The machinery of the pumping station was built by the Quintard Iron Works of New York City, and was installed in 1884. It consisted of four cross-compound engines of the vertical type, with Meyer cut-off valves, each of which was directly connected by means of a long connecting rod to two centrifugal pumps. The dimensions of each engine were as follows:

Diameter of high-pressure cylinder,	18 inches.	
" " low-pressure "	34 "	
Length of stroke,	34 "	
Diameter of piston rod, high-pressure cylinder,		$2\frac{1}{4}$ inches.
" " tail rod, " " "		$2\frac{1}{16}$ "
" " piston rod, low-pressure cylinder,		$2\frac{13}{16}$ "
" " tail rod, " " "		$2\frac{3}{32}$ "

The engines were designed to run at 100 revolutions per minute and to develop 400 indicated horse-power with 90 pounds steam pressure. The total capacity of the station was intended by the designers to be 64,000 cubic feet of water delivered per minute against a head of six feet.

The wheel of each centrifugal pump was five feet seven inches in diameter and had four vanes or blades, each being three feet four inches in length measured parallel to the axis. The suction inlet to the pump was a round tube four feet in diameter, connected to a square tube four by four feet on the inside, containing a gate.

The capacity of the centrifugal pumps not being sufficient to keep the Chicago River in the required condition of salubrity, an attempt was made to increase the capacity of the pumping station, and with this object in view a contract was let for removing the centrifugal pumps and substituting "Undulating" or Courtright pumps, the construction of which will be described later, and regarding which the contractor guaranteed that, with the expenditure of the same amount of power and with the use of the same engines, the volume of water delivered by each engine would be 25,000 cubic feet per minute against a head of six feet, which would be an increase in capacity of about 9,000 cubic feet, or 56 per cent. for each engine. Two centrifugal pumps, both of which were attached to engine No. 1, were removed during the winter of 1892 and 1893 and two "Undulating" pumps were substituted. The remaining centrifugal pumps were kept in position until the "Undulating" pumps had proved by experiment and use to be as represented.

The "Undulating" pump is shown in elevation in Fig. 57, with working parts shown by dotted lines, and is seen to consist of three rectangular pistons which are so constructed as to have partly a rectilinear and partly an oscillatory motion. This peculiar motion was produced by connecting each rectangular piston to a revolving crank by a perpendicular arm and also

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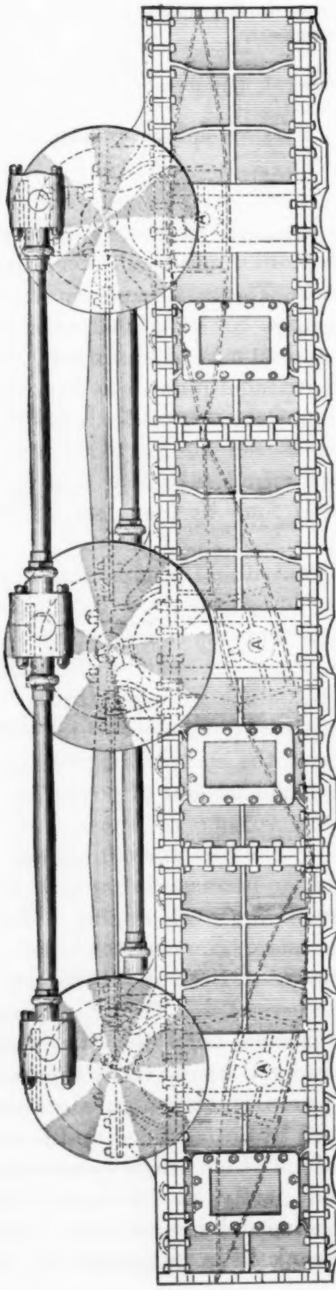


ELEVATION PLAN OF COURTRIGHT PATENT UNDULATING PUMPS AS ERECTED AT BRIDGEPORT PUMPING STATION, CHICAGO, ILL., FOR SEWERAGE PURPOSES.

Length 21 feet, Breadth 51 inches, Depth 31 inches, Capacity 12500 cubic feet per Minute.

FIG. 57.

joining it with a pivoted connection to a sliding cross-head, arranged to move perpendicularly across the case.

The cranks to which the pistons are connected are joined by connecting rods and set at angles of 120 degrees to each other, which causes the reciprocating and tilting movements of the pistons to take place alternately, producing a wavelike motion, the effect of which is to propel forward, with considerable force, any water which may enter the pump. The pump is double-acting and delivers water both on the down and up strokes of the pistons, and, except for the leakage which takes place between the pistons and the sides of the case and under the ends of the piston, is positive in its action. It had no valves in the in-take or in the discharge pipe. Power for driving the pump was obtained by a geared connection to the main shaft of engine No. 1, the gearing being so proportioned that 100 revolutions of the engine would drive the pump shafts at a speed of 80 revolutions. The case of the pump was set at an inclination of about 18 degrees to the horizontal and sufficiently low to be entirely submerged at its lower end. The dimensions of each "Undulating" pump were as follows:

Rectangular section of cast iron case, 4 feet $3\frac{5}{8}$ inches x 2 feet $8\frac{1}{4}$ inches high.

Length of case, 24 feet. Built of (3) sections.

Piston, dimensions in horizontal section, 8 feet $\frac{5}{8}$ inch x 4 feet 3 inches.

Distance from crank centre to guide centre on piston, 2 feet 6 inches.

Throw of crank, 8 inches.

Length of stroke, 16 inches.

Clearance outside of pistons, and at end of stroke, $\frac{5}{16}$ inch.

Area of leakage space—

Sides of pistons, 48 feet x $\frac{5}{16}$ inch	1.25	square feet.
Top and bottom of case, 13 feet $10\frac{7}{8}$ inches x $\frac{5}{16}$ inch	.36	" "
End of paddles, 8 feet 6 inches x $\frac{3}{8}$ inch (average)	.25	" "
Total	1.86	" "
Area of clearance space on sides of case	3.72	" "

Capacity of single pump calculated from piston displacement when in horizontal position and without allowance for leakage or slip—

Per stroke	95.28	cubic feet.
Per revolution	190.56	" "
Per 80 revolutions (one minute), rated capacity	15,245.6	" "
Per 41.4 " " " actual speed	7,889.2	" "

Calculated leakage through clearance space under a head of 4 feet, 80 strokes per minute, pump at rest—

$$* \; Q = 0.81 \sqrt{2gh} = 0.81 \times 8.03 \times 2.$$

Leakage per second through 1 square foot	13.009	cubic feet.
Leakage per minute through 1 square foot	780.54	" "
Leakage per minute through 3.72 cubic feet	2,903.6	" "
Capacity of 1 pump, 80 revolutions, less calculated leakage	12,342	" "
Capacity of 2 pumps, 80 revolutions, less calculated leakage	24,684	" "
Allowance for leakage and slip in capacity estimate from displacement above rated capacity	21.9	per cent.
Calculated leakage, compared with estimated capacity	23.9	"
Capacity calculated by displacement, 2 "Undulating" pumps, at 41.4 revolutions per minute	15,778.4	cubic feet.
Ditto, corrected by leakage as above	12,874.8	" "
Actual water delivered per minute by trial, 41.4 revs.	10,470	" "
† Additional loss due to slip	15.2	per cent.
Loss due to slip and leakage	33.7	" "

Inlet tube—

Top of tube below surface of water on inlet side, 3 feet $11\frac{5}{8}$ inches	3.967 feet.
Water above datum	0.93 "
Tube below datum	3.037 "
Area of tube, 4 x 4 feet	16 square feet.
Depth of water to centre of entrance tube	6 feet 1 inch.

Calculated supply of water to each inlet tube on supposition that pump cannot raise water by suction—

$$* \; Q = .81 \text{ (area) } \sqrt{2gh} = .81 \times 16 \times 8.03 \sqrt{h} = 253.7 \sqrt{h} \text{ cubic feet per sec.}$$

When depth $h = 6$ feet, $Q = 16{,}610$ cubic feet per minute.
When " $h = 5$ " $Q = 13{,}150$ " " " "
When " $h = 4$ " $Q = 12{,}450$ " " " "
When " $h = 3$ " $Q = 11{,}780$ " " " "

---

* This coefficient is taken from experiments of Weisbach. See *Mechanics of Engineering*, vol. i., page 854, for flow of water through short cylindrical tubes with complete contraction.

† This is the percentage which the actual capacity, by trial, fell short of the calculated capacity less the calculated leakage.

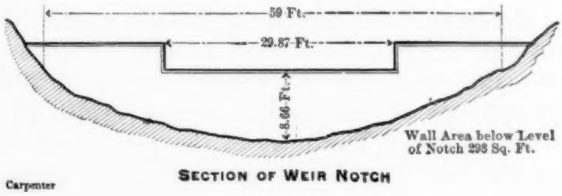
METHODS OF TESTING.

In order to test the capacity of the pumps and also to afford a working pressure in accordance with contract specifications, it was deemed necessary to build a weir. This weir was constructed at a distance of 634 feet below the engine-house by driving three rows of large piles across the channel at right angles to the stream, fastening waling pieces to the middle row and driving Wakefield sheet piling of two-inch planks, so as to form a tight dam completely across the channel. A rectangular notch was then cut in the sheet piling; the bottom was made truly horizontal and about 3½ feet below the top of the sheet piling. The down-stream side of the bottom and vertical edges of the notch were then bevelled to a thickness of about one-half inch and shod with an iron plate projecting beyond the wood, so as to give a free overfall. The plate was placed truly horizontally at the crest of the weir and vertically at the side. The elevation of the weir crest was then 5.266 feet above the Chicago city datum; the length of the weir on the crest, 29.87 feet; depth of water back of weir crest, 8.66 feet; width of canal at level of crest, 59 feet. The piles in the row above the weir were cut down to 4½ feet below the level of the crest, except near the shore, and those on the lower side were cut down a sufficient amount to permit free discharge of the overfall. The middle row of piles was then braced to the upper row near the shore, and to the lower row the entire distance across. An apron, built of plank, was placed on the lower side, about four feet below the crest of the weir, to receive the overfall and prevent scouring by the force of the current.

A hook gauge with its zero set level with the crest of the weir was placed on the right bank, in a box three feet by three feet, made of two-inch plank, sunk in the earth near the shore. A two-inch iron pipe extended out into the stream from near the bottom of the box, and admitted the water freely and maintained the same level in the box as existed in the canal, as was proved by repeated trials. The hook gauge was located about forty feet distant from the weir. During the test the hook gauge was read every five minutes by duplicate observers.

Since the writer was not able to find records of any calibration of a weir notch of the size of the one constructed for this test, and, furthermore, since the conditions of its use were somewhat

different from those of which records were to be had, it was deemed advisable and necessary to obtain the coefficients of discharge by a special calibration. This weir was constructed across a running stream, and the length of its notch was nearly equal to the width of the original, undammed stream (see Fig. 58). The bottom contraction of the weir in question was perfect, the end contraction decidedly imperfect. From its peculiar position and dimensions, it was suspected that it might be affected to some considerable extent by the bottom and sides of the stream acting as guides for the water and in such a manner as to increase the coefficient of discharge as compared with that of a weir situated on the side of a basin, or reservoir of great area. As weirs of this character, although seldom calibrated, have frequently to be constructed in order to measure the discharge from large pumping engines and also the amount



SECTION OF WEIR NOTCH

FIG. 58.

of water flowing in small streams, the calibration is, no doubt, a matter of somewhat general interest.

The weir used in the test was located at a distance of 634 feet from the engine-house, and the basin between the weir and engine-house was of considerable extent. The writer decided that, by making an accurate survey of this basin and determining the cubic contents for each tenth of a foot above the crest of the weir, it would be possible, by noting the time required for the water to fall a given distance, to compute the coefficient of discharge. Such a survey was made by a party of engineers in the charge of Mr. D. W. Church, C.E., and the results were later checked by an entirely independent survey, so that all probable errors from this source were eliminated. The computations of volumes resulting from this survey are given in column 2, Table 2. At a convenient time, the basin above the weir was filled, by operating all the pumps, to a height somewhat greater than 2.0 feet above the crest. The pumps were then all

stopped, the inlet gates were closed, and observations of the hook-gauge readings were taken at intervals of thirty seconds during the entire time the surface of the water was falling to the level of the crest of the weir; it was also continued some time after the water reached the level of the crest in order to determine the leakage loss. This test was repeated to insure accuracy, the observation log being given in the table, page 266, and the average results in table No. 3; they are also shown on the diagram, Fig. 59. The observations indicated a very small loss by leakage, as it required one hour and three minutes for the water to fall 0.073 foot below the level of the crest. On the supposition that the leakage is in proportion to the square root of the depth of the water, we have the following as the amount of leakage for various heads:

Depth on crest.	Leakage per minute, cubic feet.
0.	51.5.
0.5	52.7
1.0	54.5
1.5	55.5
2.0	57.0

Mr. John Ericson,* Asst. City Engineer of Chicago, considered, from a study of the observations, that the leakage varied from 50 to 53 cubic feet per minute as the head varied from zero to two feet above the crest. As there were more than 10,000 feet of water flowing over the weir per minute during the entire test, his estimate and the one above differ by an exceedingly small fraction. The principal calculations were made with the allowance for leakage adopted by Mr. Ericson, and it has not been considered necessary to revise this computation, since the greatest error from this source cannot exceed one three-hundredth part of one per cent., which is many times less than the least error of observation.

METHODS OF COMPUTING COEFFICIENT OF DISCHARGE.

The observations taken as explained gave the volume of water discharged for certain ranges of head at intervals of half-minutes of time. Graphical diagrams were constructed from which the approximate coefficients of discharge were obtained; the coefficients were also computed by reducing the ordinary formulæ for discharge to a series of terms and making an approximate integration by Simpson's rule after successively

* City Engineer, 1897 and 1898.

substituting the various values. This latter work was performed by Mr. D. W. Church and engineers in charge of Mr. John Ericson, who extended the series from which the computation was made so far that the numerical results of computation were in error less than 0.02 per cent.; *i.e.*, were carried two places beyond the probable limit of error of observation. All computations were carefully checked to prevent error. The results only are given in the following tables. The method of computing was as follows: Francis' formula for discharge over a weir was used without correction for velocity of approach for heads less than one foot and with correction for velocity of approach for heads greater than one foot. As will be perceived later, this latter correction was in all cases exceedingly small. The formula used was as follows for cases where no velocity of approach is considered:

$$Q = c\,(b - 0.2H)\,H^{\frac{3}{2}},$$

and for cases where velocity of approach is considered,

$$Q = c\,(b - 0.2H)\,[(H + h)^{\frac{3}{2}} - h^{\frac{3}{2}}]\,;$$

and in which Q equals discharge in cubic feet per second, b equals length of weir, equals 29.875 feet, H equals hook-gauge reading, h equals head due to velocity at a point where H was measured, c equals coefficient whose value is sought.

In the above formula, let V equal total discharge in time t, then will

$$V = Qt,$$

from which

$$dV = Qdt = c\,(b - 0.2H)\,H^{\frac{3}{2}}\,dt$$

for cases with no velocity of discharge,

$$dV = Qdt = c\,(b - 0.2H)\,[(H + h)^{\frac{3}{2}} - h^{\frac{3}{2}}]\,dt$$

for cases with velocity of discharge.

In order to abbreviate the computation, substitute y for the quantity $(b - 0.2H)\,H^{\frac{3}{2}}$ or for $(b - 0.2H)\,[(H + h)^{\frac{3}{2}} - h^{\frac{3}{2}}]$. Then will we have

$$dV = cydt\,;$$

from which

$$cdt = \frac{dV}{y},$$

$$ct = \int\frac{dV}{y}.$$

The latter expression is not an exact integral, and cannot be integrated by ordinary methods. Its value between any given limits is an area of which the abscissa are the different values of dV and the ordinates are the corresponding values of $\frac{1}{y}$.

By assigning certain values to dV, for instance $\frac{1}{10}V$, which corresponds to certain limiting values of H, a corresponding value of y can be computed from the observations. From these results a series may be formed by Simpson's rule, which may be extended to any number of terms, of which the integration may be approximated with an accuracy which depends upon the number of terms, the resulting series being as follows:

$$Ct = \int \frac{dV}{y} = \frac{V}{10}\left(\frac{1}{y'} + \frac{1}{y''}\right) + 2\left(\frac{1}{y_3} + \frac{1}{y_5} + \frac{1}{y_7} + \frac{1}{y_9}\right)$$
$$+ 4\left(\frac{1}{y_2} + \frac{1}{y_4} + \frac{1}{y_6} + \frac{1}{y_8} + \frac{1}{y_{10}}\right) +$$

The results of the various calculations, extended to three decimal places, are given in the tables No. 3 and No. 4.

LOG OF OBSERVATIONS OF FALL OF WATER ABOVE WEIR.—PUMPS NOT RUNNING.

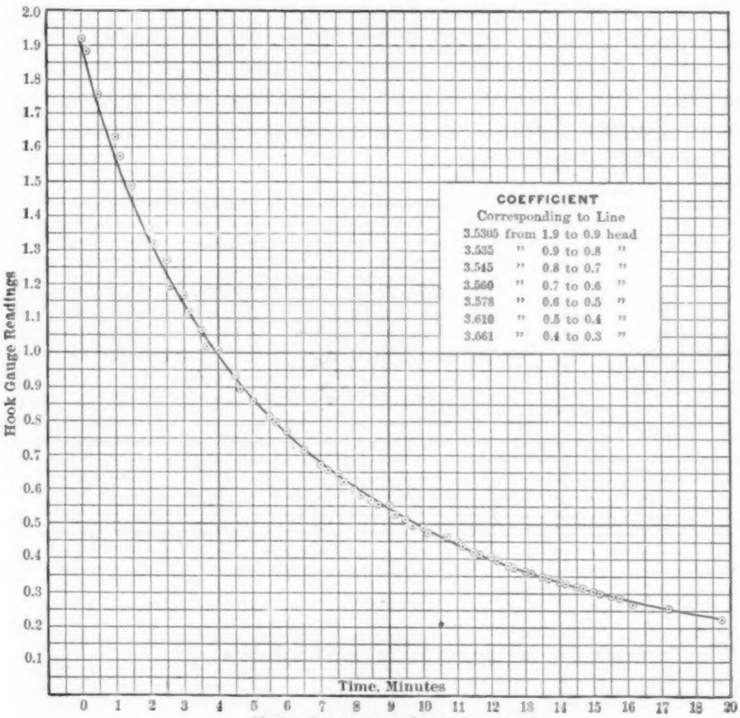
				Test for Leakage.	
Time P.M.	* Hook Gauge.	Time P.M.	* Hook Gauge.	Time P.M.	Elevation Surface below Gauge.
2.40	1.884	3.12.5	1.913	1.00	0.012
2.40.5		3.13	1.757	1.01	0.008
2.41	1.574	3.13.5	1.630	1.05	0.009
2.41.5		3.14	1.492	Weir stopped flowing	
2.42	1.315	3.14.5	1.357	1.07	0.012
2.42.5	1.194	3.15	1.264	1.12	0.024
2.43	1.120	3.15.5	1.166	1.31	0.044
2.43.5	1.016	3.16	1.068	1.42	0.060
2.44		3.16.5	1.002	1.53	0.068
2.44.5	0.902	3.17	0.936	1.55	0.070
2.45		3.17.5	0.864	2.00	0.077
2.45.5	0.804	3.18	0.816	2.10	0.085
2.46		3.18.5	0.770		Fell 0.073 ft. in 1 hr. 3 mins.
2.46.5		3.19	0.714		
2.47	0.662	3.19.5	0.675		
2.47.5	0.625	3.20	0.644		
2.48	0.585	3.20.5	0.600		
2.48.5	0.560	3.21	0.567		
2.49	0.532	3.21.5	0.545		
2.49.5	0.500	3.22	0.512		
2.50	0.478	3.22.5	0.487		
2.50.5	0.454	3.23			
2.51	0.430	3.23.5	0.442		
2.51.5	0.410	3.24	0.415		
2.52	0.395	3.24.5	0.403		
2.52.5	0.377	3.25	0.383		
2.53	0.355	3.25.5	0.360		
2.53.5	0.344	3.26	0.346		
2.54	0.330	3.26.5	0.335		
2.54.5	0.311	3.27	0.317		
2.55	0.300	3.27.5	0.303		
2.55.5	0.290	3.28	0.294		
2.56	0.274				
2.56.5	0.255				

NOTE.—By first observations, time of fall from 1.884 to 0.3 ft., fifteen minutes. By second observations, time of fall from 1.913 to 0.303 ft., fifteen minutes. Intermediate observations in second set taken with great care.

* 0 of hook gauge at level of crest of weir.

The coefficients as calculated separately for heads varying by 0.1 of a foot from a depth of 2 feet to a depth of 0.25 foot vary within the limits 3.43 and 3.7, which variation can no doubt be explained by irregularities in reading the hook gauge at the intervals of time which elapsed while the water was falling and also in slight errors in determining the time intervals. Regarding

the limits of error in the observation, it may be said, firstly, that the errors in measuring the volumes used in the calculations were necessarily very small. In the hook-gauge readings which were made as the water was falling, it is quite probable that intermediate readings taken between a head of 2 feet and 1 foot may in some cases be as much as 0.02 foot in error owing to the rapidity of the fall between those stages and the consequent



HOOK GAUGE AND TIME READINGS
Taken while Basin above Weir was Emptying.

FIG. 59.

difficulty of having the point of the hook at the surface of the water when time was called at the half-minute or minute, although warning was given ten seconds before time was called. The actual log of observations plotted with reference to time and head is given in Fig. 59, and it is seen that the results produce a very smooth curve, slight variations at certain intervals affecting only the single observation. The probable error in time interval for the entire reading does not exceed five seconds.

The coefficients, computed from the separate observations, are reduced by drawing a smooth curve through the calculated results to what are believed to be probable and average values, free, to a great extent, from accidental errors of observations. These results are given in Table 4.

MEASUREMENT OF DISCHARGE WITH ROD FLOATS.

During the entire time of the test rod floats were run at distances about four feet apart, measured across the channel. The course of these floats were accurately noted by an observer on the shore with a transit, and the observations were reduced by use of Francis' formula with the greatest care by engineers in charge of Mr. D. W. Church.

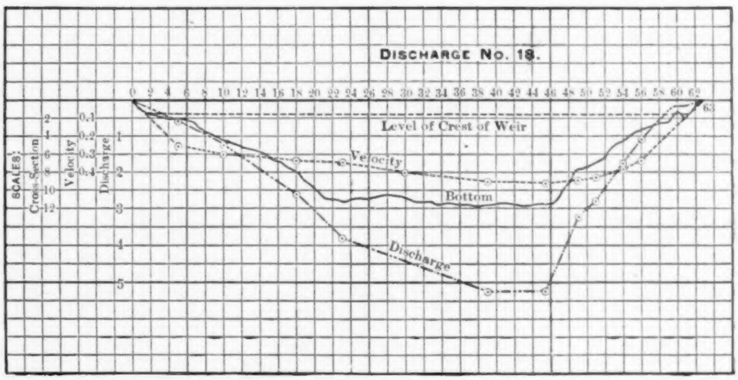


FIG. 60.

The formula for mean velocity is as follows:

$$V_m = V_r\left(1.0116 - 0.116\sqrt{\frac{d-I}{d}}\right),$$

in which

V_r = observed velocity. d = depth.
V_m = mean velocity. I = immersion of rod.

On a diagram of the cross section of the canal the mean velocity and discharge, as computed for each observation, were plotted to a suitable scale. The integration of the curve drawn through the points thus obtained gave the total discharge corresponding to the observation. This method is illustrated in Fig. 60.

The results as calculated by the formula for the discharge,

using rod floats, were 2.7 per cent. less than that obtained with the coefficient of the calibration.

The results of the observations with the rod floats are given in Tables 1 and 2.

EFFICIENCIES OF THE PUMPING MACHINERY.

The amount of water pumped and the efficiency of the different pumps used at the station are given in the following table. The tests which were made show the indicated horse-power for each engine, corresponding to different delivery heads and

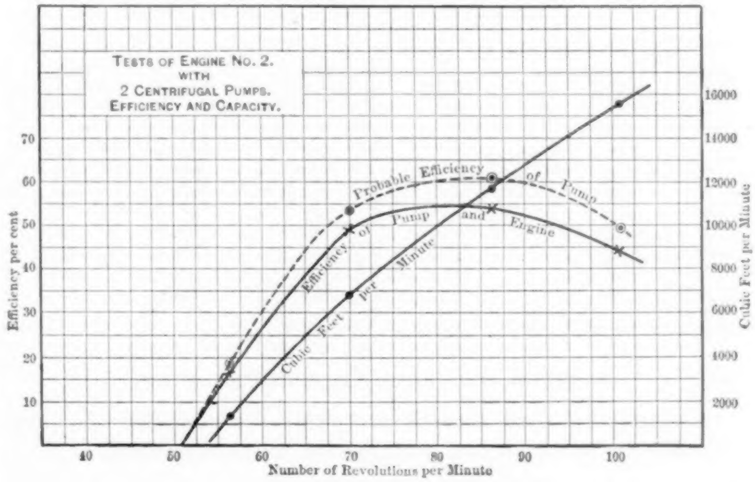


FIG. 61.

different volumes of water discharged. The work of raising the water against the head for the stated conditions was computed, from which the efficiency of the entire plant, including both engine and pump, was calculated. The friction of the engine could not be determined under the conditions existing at the time the test was made, so that the efficiency of the pump alone could not be computed without a hypothetical allowance for friction. On the supposition that the engine friction is 10 per cent. of the indicated horse-power, an amount which is known to be very little in error, a table of probable efficiency of the pumps independent of the engine was computed and is given. The curves of efficiency and capacity of the pumps operated by engine No. 2 are shown in the accompanying diagram (Fig. 61).

TABLE OF EFFICIENCIES OF PUMPING MACHINERY.

No. of Test.	No. of Engine.	Kind of Pump.	Indicated H. P.	Revolutions per Minute.	Depth over Weir.	Delivery Head, in Feet.	Cubic Feet per Min.	Work of Pumping H. P.	Efficiency, Engine and Pump.
1	1	Undulating	270.7	41.4	1.405	5.645	10,538	112.9	41.7
2	2	Centrifugal	412.2	100.8	1.925	6.108	15,680	182.1	44.2
3	2	"	240.6	86.4	1.523	5.80	11,898	131.3	54.5
4	2	"	136.1	70.02	1.064	5.18	6,764	66.8	49.1
5	2	"	72.1	56.01	0.320	4.41	1,421	11.9	16.5
6	3	"	344.6	99.7	1.824	5.98	14,969	170.8	51.2
7	3	"	208.9	84.4	1.416	5.62	10,606	113.5	54.3
8	4	"	212.9	82.4	1.322	5.37	9,440	96.0	45.3

No. of Test.	No. of Engine.	Kind of Pump.	Probable Delivered Horse-power.	Work of Pumping Horse-power.	Probable Efficiency of Pump.
1	1	Undulating........	243	112.9	45.4
2	2	Centrifugal	371	182.1	49.1
3	2	"	216.5	131.3	61.1
4	2	"	122.5	66.8	54.4
5	2	"	64.9	11.9	18.4
6	3	"	310.2	170.8	55.2
7	3	"	188	113.5	60.0
8	4	"	192	96.0	50.0

FORMULÆ FOR DISCHARGE THROUGH WEIRS.

In connection with various computations made for discharge over the weir numerous authorities were consulted, and an abstract of the various formulæ and coefficients relating to similar cases are appended for convenience of reference.

The formula ordinarily employed for computing the discharge of water through a rectangular weir, in case there is no velocity of approach at the point where the hook gauge is located, is as follows

$$Q = c \cdot \tfrac{2}{3}\sqrt{2g} \cdot bH^{\frac{3}{2}} = c \cdot \tfrac{2}{3}(8.025)bH^{\frac{3}{2}} = 5.35cbH^{\frac{3}{2}}, \quad (1)$$

in which Q equals the quantity discharged in cubic feet per second, b is the length of the weir, H the height or head of water flowing over the weir (corresponding in the following experiments to the hook-gauge reading), c the coefficient of discharge.

The value of c, the coefficient of discharge, varies with the length of the weir and with the depth of water flowing over the crest: it is less for short weirs than for long ones, and is greater for low heads than for high heads. The following table, copied

from Merriman's *Hydraulics*, gives the values of the coefficient of discharge, c, as deduced by Hamilton Smith, Jr., from experiments by Lesbros, Francis, Fteley, and Stearns. The table of coefficients for weirs with end contractions shows a variation, from the highest heads on the shortest weirs to the lowest heads on the longest weirs, from 0.587 to 0.656, and without end contractions from 0.652 to 0.623.

COEFFICIENT FOR CONTRACTED WEIRS.

Effective Head, in Feet.	Length of Weir in Feet.							
	0.66	1	2	3	5	10	19	30*
0.1	0.632	0.639	0.646	0.652	0.653	0.655	0.656	0.657
0.15	.619	.625	.634	.638	.640	.641	.642	0.643
0.2	.611	.618	.626	.630	.631	.633	.634	0.635
0.25	.605	.612	.621	.624	.626	.628	.629	0.630
0.3	.601	.608	.616	.619	.621	.624	.625	0.626
0.4	.595	.601	.609	.613	.615	.618	.620	0.622
0.5	.590	.596	.605	.608	.611	.615	.617	0.619
0.6	.587	.593	.601	.605	.608	.613	.615	0.617
0.7		.590	.598	.603	.606	.612	.614	0.616
0.8			.595	.600	.604	.611	.613	0.615
0.9			.592	.598	.603	.609	.612	0.615
1.0			.590	.595	.601	.608	.611	0.614
1.2			.585	.591	.597	.608	.610	0.615
1.4			.580	.587	.594	.602	.609	0.616
1.6				.582	.591	.600	.607	0.614

* Not given in table. Coefficient calculated by differences by the writer.

TABLE OF COEFFICIENTS FOR WEIRS WITHOUT END CONTRACTION.

Effective Head, in Feet.	Length of Weir in Feet.						
	2	3	4	5	7	10	19
0.1				0.659	0.658	0.658	0.657
0.15	0.652	0.649	0.647	.645	.645	.644	.643
0.2	.645	.642	.641	.638	.637	.637	.635
0.25	.641	.638	.636	.634	.633	.632	.630
0.3	.639	.636	.633	.631	.629	.628	.626
0.4	.636	.633	.630	.628	.625	.623	.621
0.5	.637	.633	.630	.627	.624	.621	.619
0.6	.638	.634	.630	.627	.623	.620	.618
0.7	.640	.635	.631	.628	.624	.620	.618
0.8	.643	.637	.633	.629	.625	.621	.618
0.9	.645	.639	.635	.631	.627	.622	.619
1.0	.648	.641	.637	.633	.628	.624	.619
1.2		.646	.641	.636	.632	.626	.620
1.4			.644	.640	.634	.629	.622
1.6			.647	.642	.637	.631	.623
1.8							
2.0							

A formula which is extensively used in America for computing the flow through weirs was given by Francis in 1854, and was deduced by him from experiments on weirs not less than 10 feet long and with heads ranging from 0.4 to 1.6 feet. Francis' formulæ are as follows:

First, for weirs without end contractions—

$$Q = 3.33bH^{\frac{3}{2}} = 0.622bH^{\frac{3}{2}}\sqrt{2g};$$

and, second, for weirs with two end contractions—

$$Q = 3.33(b - 0.2H)H^{\frac{3}{2}} = .622\sqrt{2g}(b - 0.2H)H^{\frac{3}{2}}.$$

In this latter formula it is supposed that the effect of each end contraction is to shorten the effective length of the weir by an amount equal to $0.1H$.

CORRECTION FOR VELOCITY OF APPROACH AND AREA OF NOTCH.

Where the water approaches the weir with a certain velocity, the coefficient of discharge is to be increased. The methods employed by different authorities for this computation are as follows:

Let h equal the square of the velocity of the current in feet per second divided by $2g(64.32)$, then will the flow over the weir be as follows, as given by Rankine—

$$*Q = 5.35cb\left[(H + h)^{\frac{3}{2}} - h^{\frac{3}{2}}\right] = 3.33b\left[(H + h)^{\frac{3}{2}} - h^{\frac{3}{2}}\right] \text{ when } c = 0.622;$$

as given by Francis—

$$\dagger Q = 3.33(b - 0.2H)\left[(H + h)^{\frac{3}{2}} - h^{\frac{3}{2}}\right];$$

as given by Hamilton Smith, Jr.—

$$\ddagger Q = \tfrac{2}{3}c(H + 1.4h)^{\frac{3}{2}}b\sqrt{2g} = 5.35cb(H + 1.4h)^{\frac{3}{2}}.$$

Some experiments were made at Sibley College to determine the effect of the velocity of approach on the coefficient of discharge of 8-inch notches, constructed so as to be interchangeable and having the same coefficient of discharge when used under the same conditions. These notches were arranged so that the same water should flow through each, approaching one

* Rankine's *Civil Engineering*, page 683.

† Merriman's *Hydraulics*, page 113.

‡ Merriman's *Hydraulics*, page 109.

with no appreciable velocity and the other with considerable velocity. The results of this test, which are appended to the paper, indicate a correction somewhat greater than that given by Smith. The formula found to apply very accurately, with velocity of approach from 0.2 to 0.8 foot per second, was

$$Q = \tfrac{2}{3}c\,(H + 3.7h)^{\frac{3}{2}}\, b\sqrt{2g} = 5.35cb\,(H + 3.7h)^{\frac{3}{2}}.$$

The dimensions of the notch through which the flow takes place, compared with that of the stream, has considerable influence on the coefficient of discharge. Regarding this, Weisbach * makes the following statement: "The most extensive experiments were made by d'Aubuisson and Castel. From these, d'Aubuisson concludes that for overfalls whose width is not greater than one-third that of the canal or of the wall in which the weir is placed, we can put the coefficient of discharge $c = 0.60$; that, on the contrary, when the overfall extends across the whole wall or has the same width as the canal, we must take $c = 0.665$; that finally, when the relations between the width of the notch and that of the canal differ from the above, the coefficient of efflux is very varied, the extremes being 0.58 and 0.66. The experiments made in 1853 and 1854 at Hanswyk, upon overfalls 3 to 6 meters wide, under a head of 0.1 to 1.0 meter, gave $c = 0.64$ to 0.65."

Weisbach corrects for imperfect contraction and area of notch as well as for the velocity of approach by using a factor which increases the effective length of the weir instead of the head. Thus in vol. i., *Mechanics of Engineering*, page 845, he gives for the discharge of a weir with end contractions,

$$Q = \tfrac{2}{3}c\,\sqrt{2gh^3}\,(1 + 1.718n^4)\,b,$$

and for one without end contraction,

$$Q = \tfrac{2}{3}c\,\sqrt{2gh^3}\,(1.041 + 0.3693n^2)\,b.$$

In the above formulæ, c is the coefficient of discharge for no velocity of approach and perfect contraction, and n is the area of cross-section of the notch divided by the area of cross-section of the stream. Weisbach gives for the value of c for overfalls of great width, as obtained by Eytelwein, 0.63, and by Bidone 0.62, the average being 0.625.

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* *Mechanics of Engineering*, vol i., page 834.

The correction given for dimensions of notch and the velocity of approach by Weisbach was, as he states, deduced from experiments made at Leipzig in 1843. It is in every case over 4 per cent. as compared with a weir with perfect contraction, but is considerably less than the corrections used by others for a weir with end contractions.

For convenience of computation, Weisbach gives the following tables of factors, which, if multiplied by the coefficient c of discharge without velocity of approach, will give a new coefficient corrected for velocity of approach.

TABLE OF FACTORS.

Values of n.	Correction Factors.	
	With End Contraction.	Without End Contraction.
0.00	1.000	1.041
0.05	1.000	1.042
0.10	1.000	1.045
0.15	1.001	1.049
0.20	1.003	1.056
0.25	1.007	1.064
0.30	1.014	1.074
0.35	1.026	1.086
0.40	1.044	1.100
0.45	1.070	1.116
0.50	1.107	1.133

The methods of correcting for velocity of approach given by Rankine and Francis are substantially identical; that given by Smith and that obtained by calibration in Sibley College are substantially different and considerably greater.

During the test the mean velocities of approach for different readings of the hook gauge were found to be as given in the following table :

TABLE.

Reading of Hook Gauge.	Value of 100n, Weisbach's Formula.	Average Velocity of Approach.	Head Corresponding to Velocity of Approach.
Feet.	Per Cent.	Feet per Sec.	Feet.
0.2	1.53	0.026	0.00001
0.3	2.3	0.046	0.00003
0.4	3.0	0.068	0.00007
0.5	3.68	0.095	0.00015
0.6	4.36	0.122	0.00023
0.7	5.01	0.151	0.00036
0.8	5.69	0.183	0.00052
0.9	6.23	0.211	0.00070
1.0	6.90	0.242	0.00091
1.1	7.47	0.275	0.00142
1.2	8.00	0.312	0.00151
1.3	8.57	0.345	0.00183
1.4	9.12	0.380	0.00224
1.5	9.65	0.414	0.00265
1.6	10.02	0.448	0.00310
1.7	10.65	0.480	0.00358
1.8	11.15	0.514	0.00410
1.9	11.5	0.557	0.00480
2.0	12.0	0.585	0.00533

It is to be noted that the correction for increased head due to the velocity of approach by any of the methods is very small and may be neglected without sensibly affecting the results, but the correction for dimensions of notch, especially for a weir with imperfect contraction, is of considerable magnitude. The following table shows the results of correcting in various ways for the velocity of approach, as given by the different authorities cited, from heads of 2 to 1.5 feet.

CORRECTION FOR VELOCITY OF APPROACH.

Head over Weir.	Factors for Correcting Coefficient.				
	Francis.	Smith.	Sibley College Experiments.	Weisbach.	
				Imperfect Contraction.	Perfect Contraction.
2 feet.	1.0039	1.0058	1.0148	1.0460	1.00036
1.9 "	1.0034	1.0052	1.0140	1.0458	1.00028
1.8 "	1.0028	1.0044	1.0125	1.0456	1.00025
1.7 "	1.0025	1.0040	1.0107	1.0452	1.00022
1.6 "	1.0019	1.0034	1.0090	1.0448	1.00017
1.5 "	1.0013	1.0030	1.0077	1.0450	1.00015

RESULTS OF THE CALIBRATION.

The discharge in cubic feet per minute, corresponding to the various heads or hook-gauge readings, is shown by the curve, Fig. 62, as obtained by the calibration. The coefficients corresponding to the value of c in the formula $Q = \frac{2}{3}cbh\sqrt{2gh}$ vary for different heads within the limits 0.646 and 0.658, and hence agree very closely with those obtained by d'Aubuisson for what seems to have been similar conditions. These values, reduced for velocity of the approaching water by the method which

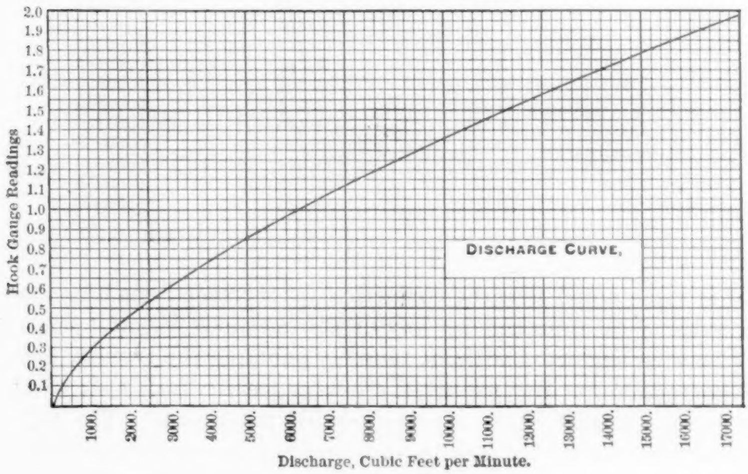

FIG. 62.

makes the greatest correction, even if the end contraction be considered as entirely wanting, give results which are greater by about two per cent. than those previously tabulated.

To compare the coefficients actually obtained with those applicable to cases with perfect contraction and no velocity of approach, some formula of reduction should be applied. That given by Francis and Rankine is theoretical, and does not seem to have been checked by experiment, but all the others were determined from experimental investigations. The Sibley College formula to which reference has been made was deduced from experiments with 8-inch notches, and for that reason may not apply with accuracy to large weirs; that given by Smith is for weirs with end contraction, and this is true to a certain

extent with that obtained in Sibley College. Those given by Weisbach have seemed to the writer to be most nearly applicable to the case, for the reason that the dimensions of the notch are given consideration, and they give results which agree closely with our calibration; for this reason they have been given the most weight in the table which follows. The table gives the coefficients which were obtained from the calibration and which would seem to be correct for the conditions referred to, with a probable error not exceeding one per cent. The unreduced coefficients are to be used in the formula,

$$Q = \tfrac{2}{3} cbh\sqrt{2gh} = Cbh^{\frac{3}{2}}.$$

In the preceding tables of coefficients given on page 272, the values correspond to that of c in the above formula. By using the formula $C\,bh^{\frac{3}{2}}$ one constant only need be used, and its application is consequently less laborious.

$$C = \tfrac{2}{3} c\sqrt{2g} = 5.25c.$$

TABLE OF COEFFICIENTS OF WEIR.

Head, in Feet.	WITHOUT REDUCTION.		VALUE OF c REDUCED.	
	Value of c.	Value of C.	Sibley College Formula. Velocity Approach.	Weisbach's Formula. Imperfect Contraction.
2	0.646	3.456	0.637	0.617
1.9	0.647	3.461	0.638	0.617
1.8	0.648	3.465	0.642	0.618
1.7	0.649	3.470	0.643	0.619
1.6	0.649	3.475	0.644	0.620
1.5	0.651	3.481	0.646	0.621
1.4	0.652	3.488	0.648	0.623
1.3	0.653	3.496	0.649	0.625
1.2	0.654	3.505	0.650	0.626
1.1	0.654	3.515	0.651	0.626
1.0	0.655	3.525	0.652	0.627
0.9	0.655	3.536	0.653	0.627
0.8	0.655	3.551	0.653	0.627
0.7	0.655	3.568	0.654	0.628
0.6	0.656	3.586	0.655	0.628
0.5	0.656	3.606	0.656	0.629
0.4	0.657	3.630	0.656	0.629
0.3	0.657	3.660	0.656	0.630
0.2	0.658	3.700	0.657	0.631

CONCLUSIONS.

The general conclusions to be drawn from the results of the test and a study of previous experiments are briefly as follows:

1. The length of an overfall, if great in proportion to the width of the stream, has considerable effect on the results. This effect is not considered in the ordinary formula nor in that of Francis, and hence both fail to give accurate results for these conditions.

2. When the length of overfall is nearly equal to the width of the undammed stream, as in the case considered, the end contractions have little effect on the discharge, and the results correspond to weirs with imperfect end contraction.

3. A weir constructed without end contraction is better under usual conditions than one with end contraction, and is recommended for ordinary use.

4. The formula of Weisbach, as given heretofore, viz.,

$$Q = \tfrac{2}{3}c\sqrt{2gh^3}\,(1.041 + 0.3693n^2)\,b = 5.35c\,(1.041 + 0.3693n^2)\,bh^{\frac{3}{2}},$$

in which $c = 0.625$, is believed to apply to wide overfalls similar to the one described with greater accuracy than any formulæ examined. If we substitute the value of c in the formula, we shall have:

$$Q = 3.344\,(1.041 + 0.3693n^2)\,bh^{\frac{3}{2}}.$$

The application of this formula gives results which differ but slightly more than one per cent. from the extreme values of the calibration, and differ but a fraction of one per cent. from the values used throughout the test. The last column in the preceding table gives the coefficient to be substituted in the formula of Weisbach, as given above, to agree exactly with the results of the calibration, and this is seen to vary from 0.617 to 0.631 for a range of heads from 2 feet to 0.2 foot. To account for this variation, an additional term or factor would need to be introduced; this would be an additional complexity not warranted by the slight additional accuracy to be secured.

The following tables give the results of the various tests and computations referred to as follows:

Table No. 1. Discharge observations with rod float reduced by Francis' formulæ.

TABLE NO. 1.

DISCHARGE OBSERVATIONS AT CANAL PUMPING WORKS.—ROD FLOAT METHODS.—VELOCITIES REDUCED BY FRANCIS' FORMULA.

Time.			Gauge Reading, Ft. above Chicago Datum.							
No.	Date.	Hour.	Temporary at Wagon Bridge.	At Outlet of Pumping Works.	At Foot Bridge, Temporary.	Area of Middle Section, Square Feet.	Mean Velocity, Feet per Second.	Discharge, Cubic Feet per Second.	Discharge, Cubic Feet per Minute.	Engines Running and Speed.
	1893 July 3	10.10 A. M.	3.76	3.80	.....	305	2.18	684	39,840	
		11.25	3.76	3.80	.....	305	2.27	691	41,460	
		1.30 P. M.	3.76	3.82	.....	305	2.11	644	38,640	
		3.00	3.76	3 82	.....	305	2.12	648	38,880	
		4.00	3.76	3.82	.....	305	2.03	619	37.140	
		4.30	3.76	3.82	.....	305	2.10	639	38.340	
	" 5	9.10 A. M.	3.66	3.70	.....	300	1.94	581	34,860	
		9.45	3.69	3.76	....	300	2.09	628	37,680	
		10.20	3.77	3.88	.....	305	2.31	704	42,240	
		11.15	3.84	3.98	.....	310	2.40	745	44.700	
		2.45 P. M.	3.86	4.00	.....	310	2.27	705	42.300	
		3.25	3.90	4.04	.....	310	2.26	702	42,120	
1	" 11	4.20	....	.....	3.86	294.7	1.974	581.7	34,902	6 Centrifugal Pumps.
2		4.35- 4.50	....	.....	3.86	294.7	2.07	608.6	36,517	6 " "
3		4.50- 5.05	....	.....	3.86	294.7	2.243	661	39.658	6 " "
4		5.05- 5.15	....	.....	3.86	294.7	2.241	660.3	39,620	6 " "
5	" 12	11.15-11.40 A. M.	....	.....	3.86	294.7	1.933	569.5	34.172	6 " "
6		11.40-11.55	....	.....	3.86	294.7	2.057	606.6	36.369	6 " "
7		11.55 A. M.-12.10 P. M.	....	.....	3.86	294.7	2.017	594.4	35.667	6 " "
8		12.15-12.30	....	.....	3.86	294.7	1.986	585	35,103	6 " "
9		12.32-12.45	....	.....	3.86	294.7	1.980	583.4	35,004	6 " "
10		12.50- 1.10	...	.....	3.86	294.7	2.097	617.8	37,089	6 " "
11		1.15- 1.30	....	.....	3.86	294.7	2.114	622.9	37,377	6 " "
12		1.30- 1.50	....	.....	3.86	294.7	2.146	632.2	37.932	6 " "
13		1.51- 2.05	....	.....	3.86	294.7	2.126	626.5	37,592	6 " "
14		2.15- 2.30	....	.....	3.86	294.7	2,189	644.9	38,696	6 " "
15		2.34- 2.45	....	.....	3.86	294.7	2.032	598.8	35,927	6 " "
16		2.48- 3.00	....	.....	3.86	294.7	2.123	625.6	37,535	6 " "
17	" 18	10.28-11.25 A. M.	....	.....	6.70	458.6	0.3611	165.6	9.936	Eng. No. 1, 41.4 Rev's.
18		11.38 A. M.-12.30 P. M.	....	.....	6.70	458.6	0.3854	176.7	10,603	" " 1, 41.4 "
19		12.30- 1.32	...	.....	6.62	453.5	0.3929	176.2	10,690	" " 1, 41.4 "
20		1.40- 2.51	....	.....	6.71	459.2	0.3788	173.9	10.437	" " 1, 41.4 "
21		3.02- 4.00	....	.....	6.70	458.6	0.3728	170.7	10.242	" " 1, 41.4 "
22		5.30- 6.35	....	.....	7.22	491.3	0.5506	270.5	16.232	" " 2, 108 "
23		6.37- 7.32	....	.....	6.82	466.1	0.3787	176.5	10,591	" " 2, 36.4 "
24		7.35- 8.55	....	.....	6.82	466.1	0.4086	190.4	11.427	" " 2, 36.4 "
24*a*		Combinat'n 24 & 25.	....	.....	6.80	464.8	0.4043	187.9	11,275	" " 2, 36.4 "
26		10.45 P. M.-12.35 A. M.	....	.....	7.12	485.1	0.5010	243	14,586	" " 3, 99.7 "
27	" 19	12.47- 1.35	....	.....	6.71	459.2	0.3654	167.8	10,066	" " 3, 84.4 "
28		1.47- 2.31	....	.....	6.71	459.2	0.3814	175.1	10,507	" " 3, 84.4 "
29		2.40- 3.45	..	.....	6.71	459.2	0.3762	172.7	10.363	" " 3, 84.4 "
30*a*		3.55- 4.50	...	.....	6.71	459.2	0.3151	144.6	8,674	" " 4, 82.4 "
30*b*		....	..	.....	6.63	451.2	0.3155	143.3	8,599	" " 4, 82.4 "
31		5.10- 6.10	....	.....	6.63	454.2	0.3390	154	9,239	" " 4, 82.4 "
32		10.25-11.37	....	.....	6.32	434.8	0.2435	105.9	6,353	" " 2, 70.02 "

TABLE NO. 2.

ROD FLOAT OBSERVATIONS NO. 18.—METHOD OF COMPUTING DISCHARGE.

Distance out from Zero Line at Which Float Crosses Ranges.			Length of Float.	Depth of Immersion = I.	Depth of Water at Crossing Middle Range.	$\frac{d-I}{d} = D$ of Francis.	Correction for Velocity, Francis' Formula.	Observed Velocity, Feet per Second.	Corrected Velocity = V. Feet per Second.	Depth on Middle Range at Points where Velocity is Measured.	Discharge Curve Ordinate = Vd.	Areas of Trapezoids and Triangles Making up Discharge Area.
Upper.	Middle.	Lower.										
	6								○	○	○	Total.
	7							Interpolated.	0.045	0.91	0.041	
	8								0.100	1.51	0.151	
	9								0.152	1.81	0.275	1.141
	10								0.200	2.06	0.412	4.462
14	11	12	2.00	1.75	2.03	0.13	0.970	0.2665	0.2585	2.03	0.525	15.464
17	16	18	3.00	2.58	4.21	0.39	0.939	0.3187	0.2992	4.21	1.260	16.135
23½	24	25½	4.67	4.08	7.71	0.47	0.932	0.3627	0.3380	7.71	2.606	72.880
30	29	27	9.50	9.00	11.11	0.19	0.961	0.3604	0.3463	11.11	3.848	34.001
48	45	45½	10.50	10.00	11.71	0.15	0.967	0.4646	0.4493	11.71	5.262	14.842
53	51½	50	9.50	9.00	11.21	0.20	0.960	0.4831	0.4638	11.21	5.200	6.105
53	55	55	7.67	7.17	7.41	0.03	0.992	0.4464	0.4428	7.41	3.281	
60	57	57	4.67	4.08	6.61	0.38	0.940	0.4546	0.4273	6.61	2.824	7.041
61	60	58	3.00	2.58	4.71	0.45	0.934	0.4251	0.3970	4.71	1.870	2.930
62	62	58	2.00	1.75	3.21	0.45	0.934	0.3534	0.3301	3.21	1.060	
	63								0.280	2.71	0.759	
	64								0.240	2.41	0.578	
	65								0.180	2.21	0.398	
	66								0.140	1.21	0.169	
	67								0.085	1.91	0.162	
	68								0.040	0.71	0.028	
	69								0.000	0.000	0.000	1.714
Discharge, cubic feet per second												176.715

176.715 × 60 = 10,603 = Discharge per minute.

Francis' Formula for Reducing Observed to Mean Velocities:

$$Vm = Vr\left[1.0116 - 0.116\,\frac{\sqrt{d-I}}{d}\right].$$

Vr = Observed Velocity.
Vm = Mean Velocity.
d = Depth.
I = Immersion of Rod.

TABLE NO. 3.

OBSERVATIONS FOR COEFFICIENT OF DISCHARGE.

(1) Height of Water above Crest of Weir, Feet.	(2) Total Volume of Water in Basin between Weir and Pump House and above Level of Weir.	(3) Volume of Water in Basin between Each $\frac{1}{10}$ ft. and next $\frac{1}{10}$ Above.	(4) Rate of Leakage per Minute, Cubic Feet.	(5) Observed Time in which Water Dropped $\frac{1}{10}$ ft. in Emptying Basin, Minutes.	(6) Quantity that Passed Out of Basin by Leakage during Each $\frac{1}{10}$ Drop, Cubic Feet.	(7) Actual Volume Passing over Weir with Each $\frac{1}{10}$ Drop, Cubic Feet.	(8) Cubic Feet Discharged per Second, falling $\frac{1}{10}$ ft. to Head in Column 1.
2.00	90,559		53				
1.90	85,902	4,657	53				
1.80	81,257	4,644	53	0.2938	16	4,628	262
1.70	76,626	4,631	53	0.3131	17	4,614	244
1.60	72,008	4,618	52	0.3459	18	4,600	222
1.50	67,462	4,605	52	0.3712	19	4,586	206
1.40	62,810	4,592	52	0.4172	21	4,571	187
1.30	58,230	4,579	52	0.4627	24	4,555	165
1.20	53,664	4,566	52	0.5176	27	4,539	146
1.10	49,109	4,555	51	0.5847	30	4,525	129
1.00	44,568	4,541	51	0.6676	34	4,507	113
0.90	40,045	4,523	51	0.7710	39	4,484	97
0.80	35,537	4,508	51	0.9100	46	4,462	81.7
0.70	31,043	4,494	51	1.0800	55	4,439	65.5
0.60	26,565	4,479	51	1.33	68	4,411	49
0.50	22,100	4,464	50	1.69	84	4,380	38.2
0.40	17,651	4,449	50	2.24	112	4,337	30.2
0.30	13,216	4,435	50	3.20	160	4,275	22.8
0.20	8,796	4,420	50				
0.10	4,391	4,405	50				
0.00	000	4,391	50				

TABLE NO. 4.

CALCULATION OF COEFFICIENT OF DISCHARGE FROM DATA IN TABLE 3.

1	2	3	4	5	6	7	8	9	10
H = Hook-Gauge Reading.	V = Actual Volume of Water Passing over Weir, with Each $\frac{1}{10}$ Drop in Emptying the Basin, Cubic Feet.	$\frac{1}{y'} + \frac{1}{y''} + 2\left(\frac{1}{y_3} + \frac{1}{y_5} + \frac{1}{y_7} + \frac{1}{y_9}\right) + 4\left(\frac{1}{y_2} + \frac{1}{y_4} + \frac{1}{y_6} + \frac{1}{y_8} + \frac{1}{y_{10}}\right)$	* $Ct = \int \frac{dV}{y} = \frac{V}{30}\left[\frac{1}{y'} + \frac{1}{y''} + 2\left(\frac{1}{y_3} + \frac{1}{y_5} + \frac{1}{y_7} + \frac{1}{y_9}\right) + 4\left(\frac{1}{y_2} + \frac{1}{y_4} + \frac{1}{y_6} + \frac{1}{y_8} + \frac{1}{y_{10}}\right)\right]$	t = (Seconds).	t = (Minutes).	Coefficient.	Coefficient from Time Observations for Each Tenth Foot Column 4 ÷ Column 5.	Probable Value of Coefficient of Discharge in Francis' Formula.	Probable Coefficient, Ordinary Formula, $Q = Clh^{\frac{3}{2}}$.
1.9—1.8	4,628	.40290	62.145	17.602	.2933	3.5305	3.6990	3.504	3.461
1.8—1.7	4,614	.43821	67.398	19.090	.3181	3.5305	3.5103	3.506	3.465
1.7—1.6	4,600	.47793	73.285	20.757	.3459	3.5305	3.5924	3.508	3.470
1.6—1.5	4,586	.52482	80.214	22.720	.3712	3.5305	3.4279	3.512	3.475
1.5—1.4	4,571	.57992	88.373	25.031	.4172	3.5305	3.5068	3.516	3.481
1.4—1.3	4,555	.64535	98.027	27.765	.4627	3.5305	3.7131	3.520	3.488
1.3—1.2	4,539	.72441	109.651	31.058	.5176	3.5305	3.5834	3.526	3.496
1.2—1.1	4,525	.82096	123.872	35.086	.5847	3.5305	3.4409	3.532	3.505
1.1—1.0	4,507	.94104	141.349	40.037	.6673	3.5305	3.4644	3.540	3.515
1.0—0.9	4,484	1.09282	163.324	46.260	.7710	3.5305	3.5352	3.548	3.525
0.9—0.8	4,462	1.29254	192.236	54.380	.9100	3.535	3.5599	3.556	3.536
0.8—0.7	4,439	1.55849	230.647	65.060	1.080	3.545	3.5593	3.569	3.551
0.7—0.6	4,411	1.93027	283.883	79.740	1.330	3.560	3.6395	3.584	3.568
0.6—0.5	4,380	2.48365	362.591	101.330	1.690	3.578	3.5971	3.604	3.586
0.5—0.4	4,337	3.36276	485.815	134.570	2.240	3.610	3.6147	3.630	3.606
0.4—0.3	4,275	4.92442	701.760	191.690	3.200	3.661	3.7460	3.674	3.620
									3.66

* The above are correct values of Ct to within $\frac{3}{10}$ of one per cent. of the exact value of $\int \frac{dV}{y}$, as stated by Mr. Ericson (as calculated). Dividing Ct by the corresponding values of t, a coefficient may be obtained for each tenth.

TABLE NO. 5.

WATER DISCHARGED BY ENGINE NO. 1 (OPERATING COURTRIGHT PUMP), 41.40 REVOLUTIONS PER MINUTE.

1	2	3	4	5	6	7	8
Number Used by Prof. Carpenter.	Time. July 18, 1893.	Hook-Gauge Reading.	Velocity of Approach from Rod Float Observations, Feet per Second.	Leakage per Minute.	Total Cu. Ft., Delivered per Minute, Weir Measurement.	Average of Weir Measurements, Corresponding in Time to Rod-Float Measurements.	Discharge per Minute by Rod Float Measurements.
	A.M.						
1	10.15	1.354		52	9,966		10.28 A.M.
2	10.30	1.385		52	10,304		
3	10.45	1.390	0.3611	52	10,357		
4	11.00	1.392		52	10,374	10,416	9,936
5	11.15	1.415		52	10,629		
6	11.30	1.397		52	10,432		11.25
	11.45	1.392	0.3854	52	10,374		11.38
	M.						
7	12.00	1.392		52	10,374	10,404	10,603
	P.M.						
8	12.15	1.392		52	10,374		
9	12.30	1.403		52	10,495		12.30 P.M.
10	12.45	1.403		52	10,495		
11	1.00	1.415		52	10,631		
12	1.15	1.405	0.3929	52	10,521	10,533	10,690
13	1.30	1.405		52	10,521		1.32
14	1.45	1.405		52	10,521		1.40
15	2.00	1.413		52	10,612		
16	2.15	1.418	0.3788	52	10,665	10,609	10,437
17	2.30	1.408		52	10,559		
18	2.45	1.420		52	10,686		2.51
19	3.00	1.420		52	10,686		3.02
20	3.15	1.420	0.3723	52	10,686		
21	3.30	1.424		52	10,728	10,726	10,243
22	3.45	1.417		52	10,654		
23	4 00	1.437		52	10,876		4.00 P.M.
Averages					10,522	10,538	10,382
Rod Float Average					10,382	10,382	
Difference					$1\frac{35}{100}$ %	$1\frac{1}{2}$ %	

TABLE NO. 6.

Water Discharged by Engine No. 2, Operating Two Centrifugal Pumps, 100.8 Revolutions per Minute.

1	2	3	4	5	6	7	8	
Number Used by Prof. Carpenter.	Time.	Hook-Gauge Reading.	Velocity of Approach from Rod Float Measurement, Ft. per Second.	Leakage per Minute.	Total Cu. Ft. Delivered per Minute, Weir Measurement.	Average of Weir Measurements, Corresponding in Time to Rod Float Measurements.	Discharge per Minute by Rod Float Measurements.	
	J'ly 18,'93							
1	5.00 P.M.	1.926		53	16,809			
	5.05	1.935		53	16,925			
	5.10	1.920		53	16,735			
2	5.15	1.915		53	16,673			
	5.20	1.928		53	16,851			
	5.25	1.923		53	16,781		5.30 P.M.	
3	5.30	1.930		53	16,862			
	5.35	1.923		53	16,781			
	5.40	1.923	0.5506	53	16,781			
4	5.45	1.914		53	16,660			Speed
	5.50	1.930		53	16,862			
	5.55	1.934		53	16,915			reduce.
5	6.00	1.925		53	16,798	15,680	16,232	
	Averages.	....	....	....	16,802			
	6.05	1.936			16,936			
	6.10	1.797			15,178			
	6.14	1.675			13,659			
	6.20	1.587			12,604			
	6.28	1.546			12,127		6.28 P.M.	

TABLE NO. 7.

ENGINE NO. 2, OPERATING TWO CENTRIFUGAL PUMPS, 86.4 REVOLUTIONS PER MINUTE.

1	2	3	4	5	6	7	8
Number Used by Prof. Carpenter.	Time.	Hook-Gauge Reading.	Velocity of Approach from Rod Float Measurements, Ft. per Second.	Leakage per Minute.	Total Cu. Ft. Delivered per Minute, Weir Measurement.	Average of Weir Measurements, Corresponding in Time to Rod Float Measurements.	Discharge per Minute by Rod Float Measurements.
	July 18, '93						
6	6.30 P.M.	1.540		52	12,046		
	6.35	1.524		52	11,872		6.37 P.M.
	6.40	1.537		52	11,999		
7	6.45	1.537		52	11,999		
	6.50	1.537		52	11,999		
	6.55	1.519		52	11,800		
8	7.00	1.519	0.3787	52	11,800	11,958	10,591
	7.05	1.534		52	11,978		
	7.10	1.540		52	12,046		
9	7.15	1.540		52	12,046		
	7.20	1.535		52	11,988		
	7.25	1.523		52	11,851		
10	7.30	1.524		52	11,872		7.32 P.M.
	7.35	1.520		52	11,808		7.35 P.M.
	7.40	1.518		52	11,794		
11	7.45	1.530		52	11,936		
	7.50	1.530		52	11,936		
	7.55	1.530		52	11,936		
12	8.00	1.530		52	11,936		
	8.05	1.530		52	11,936		
	8.10	1.530	0.4086	52	11,936		
13	8.15	1.530		52	11,936		
	8.20	1.530		52	11,936	11,837	11,427
	8.25	1.530		52	11,936		
14	8.30	1.530		52	11,936		11,276
	8.35	1.510		52	11,696		
	8.40	1.485		52	11,410		
15	8.45	1.500		52	11,590		
	8.50	1.516		52	11,692		
	8.55	1.524		52	11,872		8.55 P.M.
16	9.00	1.503		52	11,628		
	9.05	1.497		52	11,539		
	9.10	1.510		52	11,692		
17	9.15	1.512		52	11,618		
	9.20	1.520		52	11,808		
	9.25	1.517		52	11,770		
18	9.30	1.506		52	11,650		
					11,844	11,898	11,098

TABLE NO. 8.

ENGINE NO. 2, OPERATING TWO CENTRIFUGAL PUMPS, 70.02 REVOLUTIONS PER MINUTE.

1	2	3	4	5	6	7	8
No. Used by Prof. Carpenter.	Time.	Hook-Gauge Reading.	Velocity of Approach, Feet per Second.	Leakage per Minute.	Total Cu. Ft. Delivered per Minute, Weir Measurement.	Average of Weir Measurements, Corresponding in Time to Rod Float Measurements.	Discharge per Minute by Rod Float Measurements.
	July 19, '93						
8	10.00 P.M.	1.009		51	6,427		
	10.05	1.216		51	8,488		
	10.10	1.206		51	8,384		
9	10.15	1.206		51	8,384		
	10.20			51			10.25 P.M.
	10.25	1.066		51	6,978		
10	10.30	1.087		51	7,190		
	10.35	1.116		51	7,471		
	10.40	1.005		51	6,391		
11	10.45	1.081		51	7,126		
	10.50	1.057		51	6,893		
	10.55	1.033		51	6,660		
12	11.00	1.030	0.2435	51	6,628		
	11.05	1.035		51	6,675	6,764	6,353
	11.10	1.034		51	6,668		
13	11.15	1.023		51	6,565		
	11.20	1.026		51	6,596		
	11.25	1.027		51	6,603		
14	11.30	1.013		51	6,469		
	Averages..	....	....	....	7,033		
	11.35				6,550		11.37 P.M.

TABLE NO. 9.

ENGINE NO. 2, OPERATING TWO CENTRIFUGAL PUMPS, 56.01 REVOLUTIONS PER MINUTE.

1	2	3	4	5	6
No. Used by Prof. Carpenter.	Time.	Hook-Gauge Reading.	Velocity of Approach, Feet per Second.	Leakage per Minute.	Total Cu. Ft. Delivered per Minute, Weir Measurement.
	July 19, 1893				
1	7.30 A.M.	0.317		50	1,218
	7.35	0.304		50	1,148
	7.40	0.290		50	1,071
2	7.45	0.329		50	1,286
	7.50	0.328		50	1,280
	7.55	0.283		50	1,036
3	8.00	0.328		50	1,280
	8.05	0.316		50	1,212
	8.10	0.347		50	1,387
4	8.15	0.350		50	1,405
	8.20	0.360		50	1,464
	8.25	0.350		50	1,405
5	8.30	0.335		50	1,319
	8.35	0.355		50	1,433
	8.40	0.355		50	1,433
6	8.45	0.344		50	1,370
	8.50	0.341		50	1,352
	8.55	0.346		50	1,383
7	9.00	0.324		50	1,258
	Averages...	....	....	....	1,302

TABLE NO. 10.

ENGINE NO. 3, OPERATING TWO CENTRIFUGAL PUMPS, 99.7 REVOLUTIONS PER MINUTE.

1	2	3	4	5	6	7	8
No. Used by Prof. Carpenter.	Time.	Hook-Gauge Reading.	Velocity of Approach, Feet per Second.	Leakage per Minute.	Total Cu. Ft. Delivered per Minute, Weir Measurement.	Average of Weir Measurements, Corresponding in Time to Rod Float Measurements.	Discharge per Minute by Rod Float Measurements.
	July 18, '93						
1	10.00 P.M.	1.860		53	15,953		
	10.05	1.696		53	13,907		
	10.10	1.675		53	13,663		
2	10.15	1.713		53	14,131		
	10.20	1.736		53	14,404		
	10.25	1.736		53	14,404		
3	10.30	1.798		53	15,188		
	10.35	1.819		53	15,453		
	10.40	1.824		53	15,506		
4	10.45	1.834	0.5010	53	15,633		
	10.50	1.836		53	15,654		
	10.55	1.838		53	15,686		
5	11.00	1.836		53	15,654		
	11.05	1.841		53	15,728		
	11.10	1.842		53	15,739		
6	11.15	1.845		53	15,764		
	11.20	1.840		53	15,707		
	11.25	1.849		53	15,813		
7	11.30	1.858		53	15,940		
	11.35	1.839		53	15,703		
	11.40	1.843		53	15,750		
8	11.45	1.846		53	15,781		
	11.50	1.847		53	15,792	14,969	14,586
	11.55	1.832		53	15,601		
9	12.00 Midnight.	1.830		53	15,580		
	Averages.	....	....	53	15,365		
	July 19, '93					Speed reduced.	
	12.05 A.M.	1.834		53	15,633		
	12.10	1.818		53	15,432		
	12.15	1.828		53	15,559		
	12.20	1.615		53	12,931		
	12.25	1.486		53	11,423		
	12.30	1.437		53	10,872		
	12.35	1.417		53	10,919		

TABLE NO. 11.

ENGINE NO. 3, OPERATING TWO CENTRIFUGAL PUMPS, 84.4 REVOLUTIONS PER MINUTE.

1	2	3	4	5	6	7	8
No. Used by Prof. Carpenter.	Time.	Hook-Gauge Reading.	Velocity of Approach, Feet per Second.	Leakage per Minute.	Total Cu. Ft. Delivered per Minute, Weir Measurement.	Average of Weir Measurements, Corresponding in Time to Rod Float Measurements.	Discharge per Minute by Rod Float Measurements.
10	July 19, 1893						
	12.30 A.M.	1.437		52	10,866		
	12.35	1.417		52	10,654		
11	12.40	1.404		52	10,516		
	12.45	1.405		52	10,525		12.47 P.M.
	12.50	1.406	0.3654	52	10,533		
12	15.55	1.400		52	10,463		
	7.00	1.409		52	10,569		
	1.05	1.404		52	10,516		
13	1.10	1.411		52	10,584		
	1.15	1.413		52	10,612		
	1.20	1.426		52	10,749	10,613	10,066
14	1.25	1.410		52	10,580		
	1.30	1.424		52	10,736		
	1.35	1.429		52	10,787		
15	1.40	1.414		52	10,622		1.35 A.M.
	1.45	1.427		52	10,760		1.47
	1.50	1.425		52	10,743		
16	1.55	1.412		52	10,601		
	2.00	1.415	0.3814	52	10,629		
	2.05	1.419		52	10,682		
17	2.10	1.412		52	10,601	10,593	10,507
	2.15	1.410		52	10,579		
	2.20	1.403		52	10,508		
18	2.25	1.401		52	10,474		
	2.30	1.405		52	10,525		2.31 A.M.
	2.35	1.405		52	10,525		
19	2.40	1.412		52	10,601		2.40 A.M.
	2.45	1.410		52	10.580		
	2.50	1.402	0.3762	52	10,495		
20	2.55	1.404		52	10,516		
	3.00	1.401		52	10,474		
	3.05	1.402		52	10,485		
21	3.10	1.411		52	10,586	10,612	10,363
	3.15	1.419		52	10,682		
	3.20	1.410		52	10,576		
22	3.25	1.428		52	10,770		
	3.30	1.429		52	10,787		
	3.35	1.412		52	10,601		
23	3.40	1.426		52	10,751		
	3.45	1.418		52	10,665		
	3.50	1.425		52	10,742		3.45 A.M.
24	3.55	1.417		52	10,654		
	4.00	1.425		52	10,742		
	Averages...	....	....	......	10,619	10,606	10,312

TABLE NO. 12.

ENGINE NO. 4, OPERATING TWO CENTRIFUGAL PUMPS, 82.4 REVOLUTIONS PER MINUTE.

1	2	3	4	5	6	7	8
Number Used by Prof. Carpenter.	Time.	Hook-Gauge Reading.	Velocity of Approach, Feet per Second.	Leakage per Minute.	Total Cu. Ft. Delivered per Minute, Weir Measurement.	Average of Weir Measurements, Corresponding in Time to Rod Float Measurements.	Discharge per Minute by Rod Float Measurements.
	July 19, '93						3.55 A.M.
1	4.15 A. M.	1.238		52	8,716		
	4.20	1.195		52	8,271		
	4.25	1.181		52	8,131		
2	4.30	1.264	0.3151	52	9,000		8,674
	4.35	1.318		52	9,584	8,993	8,599
	4.40	1.328		52	9,686		
3	4.45	1.310		52	9,487		
	4.50	1.318		52	9,584		
	4.55	1.311	0.3155	52	9,500		4.50 A.M.
4	5.00	1.313		52	9,525		
	5.05	1.335		52	9,754		5.10 A.M.
	5.10	1 338		52	9,796		
5	5.15	1.346		52	9,881		
	5.20	1.347		52	9,889		
	5.25	1.340		52	9,807		
6	5.30	1.355		52	9,980		
	5.35	1.340		52	9,807		
	5.40	1.349		52	9,919	9,887	9,239
7	5.45	1.345	0.3396	52	9,870		
	5.50	1.343		52	9,860		
	5.55	1.343		52	9,860		
8	6.00	1.356		52	9,987		
	6.05	1.343		52	9,860		
	6.10	1.358		52	10,019		
9	6.15	1.341		52	9,817		6.10 A.M.
	6.20	1.353		52	9,966		
	6.25	1.354		52	9,976		
10	6.30	1.353		52	9,966		
	Averages.	....	....	....	9,625	9,440	8,837

TABLE NO. 13.

SUMMARY OF AVERAGES FOR COMPARISON.—DISCHARGE IN CUBIC FEET PER MINUTE.

	Discharge Corresponding in Time to Rod Floats.	Rod Float Measurement.	See Table.
	Cu. Ft.	Cu. Ft.	
Courtright Pumps....................	10,538	10,382	No. 5
Centrifugal Pumps on Engine No. 2....	15,680	16,232	No. 6
" " " "	11,898	11,098	No. 7
" " " "	6,764	6,353	No. 8
Centrifugal Pumps on Engine No. 3....	14,969	14,586	No. 10
" " " "	10,606	10,312	No. 11
" " " "	9,440	8,837	No. 12
Average..........................	11,414	11,114	
Rod Float Average..................	11,114		
Difference per cent......	$2\frac{7}{10}$		

APPENDIX.

SIBLEY COLLEGE EXPERIMENTS FOR EFFECT OF VELOCITY OF APPROACH.

The results of the experiment to determine effect of velocity of approach, to which reference has been made, are given in the following pages.

Because of the discrepancy referred to in the coefficients given for velocity of discharge, an experiment was made in Sibley College for determining the effect of the velocity of discharge on the results. Two weir notches of exactly the same kind and size, and perfectly interchangeable, each with a length of eight inches, were made: one of these was placed on a large tank, the area of whose surface was so great compared with the area of the discharge as to represent the case of discharge from still water; the other was placed across a trough having a trapezoidal cross-section similar in many respects to that of the channel of the Chicago canal. The result gave, as the coefficient of correction for the head due to the velocity of approach, $3.7h$, instead of $1.4h$, as given by Hamilton Smith, Jr. The formula for the quantity of water discharged per second being

$$Q = \tfrac{2}{3}c(H + 3.7h)^{\frac{3}{2}} b\sqrt{2g} = 5.35cb(H + 3.7h)^{\frac{3}{2}},$$

in which H = head over weir, and h = head due to velocity of approach. The observations and results are shown graphically in Figs. 63 and 64.

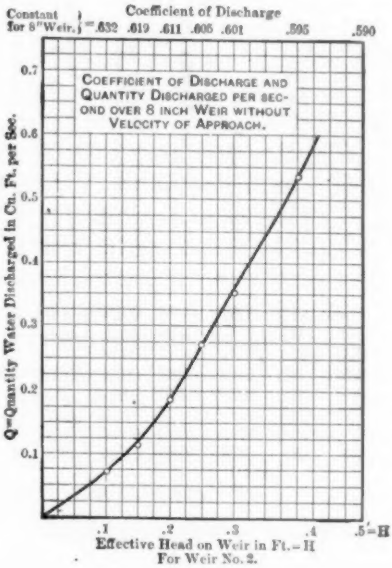

FIG. 63.

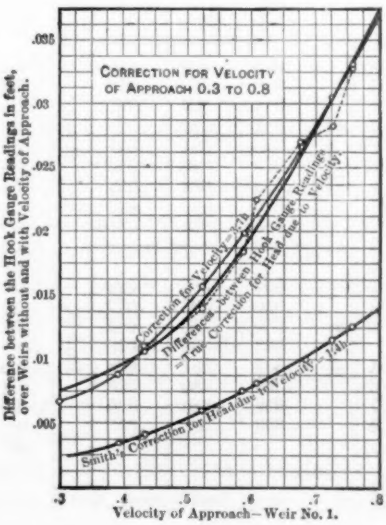

FIG. 64.

Result Sheet of Weir Test.

Weir No. 1 has velocity of approach.
Weir No. 2 has no velocity of approach. } Observer, P. G. Wilcox, M.E.

	Average Hook-Gauge Reading No. 1 Weir = H.	Average Hook-Gauge Reading Weir No. 2 = H'.	Quantity of Water Discharged, Cu. Ft. per Sec. Figured from Weir Readings No. 2 = Q.	Area of Cross-Section of Water in Tank Containing Weir No. 1 — Sq. Ft. = F.	Velocity of Approach, Weir No. 1 in Feet per Sec. = $V = Q \div F$.	(Velocity)^2 = V^2.	Head Due to Velocity = h = $.01555 V^2$.	Correction for Velocity given in Merriman's *Hydraulics* = $1.4h$.	Average Difference between Hook-Gauge Readings = True Correction for Velocity. (a)	Difference between Hook-Gauge Readings ÷ h = $(H' - H) \div h$ = Constant.	Average Value of Constant Found × h = Constant × h = $3.7h$. (b)	True Correction for Velocity, $3.7h = a - b$.
A	.2105	.220	.217	.555	.391	.1529	.0024	.0033	.0095	3.95	.0088	+ .0007
B	.231	.242	.252	.582	.433	.1875	.0029	.0041	.011	3.80	.0108	+ .0002
C	.273	.287	.333	.636	.523	.2735	.0042	.0059	.014	3.35	.0157	− .0017
D	.294	.3125	.377	.643	.586	.3434	.0053	.0074	.0185	3.5	.0198	− .0013
E	.313	.335	.418	.688	.608	.3696	.0057	.00805	.0225	3.94	.0213	+ .0012
F	.358	.385	.509	.746	.683	.4665	.0072	.0101	.027	3.74	.0268	+ .0002
G	.391	.419	.574	.788	.728	.5230	.0082	.0115	.028	3.42	.0305	− .0025
H	.407	.440	.612	.809	.757	.5730	.0089	.0125	.033	3.7	.033	.000

Weir Heads in Feet.—Log Sheet.

	Height over Weir No. 1.	Height over Weir No. 2.	Difference.
Run A.	.208	.220	.012
	.211	.222	.011
	.211	.221	.010
	.212	.220	.008
	.2105	.219	.0085
	.210	.219	.009
Run B.	.228	.239	.011
	.229	.239	.010
	.231	.243	.012
	.230	.242	.012
	.232	.243	.011
	.233	.243	.010
Run C.	.269	.283	.014
	.265	.278	.013
	.283	.300	.017
	.275	.288	.013
Run D.	.294	.314	.020
	.294	.311	.017

	Height over Weir No. 1.	Height over Weir No. 2.	Difference.
Run E.	.318	.338	.020
	.316	.335	.019
	.314	.336	.022
	.311	.333	.022
	.310	.331	.021
	.310	.334	.024
	.313	.334	.021
	.313	.336	.023
	.3135	.335	.0215
Run F.	.357	.386	.029
	.356	.383	.027
	.359	.388	.029
	.362	.390	.028
	.353	.381	.028
	.360	.388	.028
	.359	.384	.025
	.359	.382	.023

	Height over Weir No. 1.	Height over Weir No. 2.	Difference.
Run G.	.395	.426	.031
	.396	.422	.026
	.393	.419	.026
	.390	.419	.029
	.389	.418	.029
	.389	.418	.029
	.386	.414	.028
Run H.	.400	.435	.035
	.404	.438	.034
	.408	.441	.033
	.412	.452	.040
	.422	.460	.038
	.407	.434	.027
	.406	.435	.029
	.405	.436	.031
	.404	.436	.032
	.405	.436	.031
	.406	.438	.032
	.408	.442	.034

DISCUSSION.

Prof. R. H. Thurston.—Professor Carpenter's paper has more importance and represents a more extensive and uniquely great investigation than its simple character and quiet statement would at first lead one to suspect. It is not only an exceptionally complete study of the behavior of a very exceptionally large weir, but it is most important as evidence of the probability—amounting almost to a certainty—that the older and simpler formula of Weisbach may be substituted with advantage for the later and more complicated expressions which have come into such extensive use, during recent years, in the measurement of flows of great volume and over very large weirs. The statement of the efficiency found for large centrifugal pumps is also a subject of much interest to the profession, and even the results obtained from the singular construction which has been oddly dubbed "Undulating pump" have some value.

I have had some knowledge of the case, and of the place and the circumstances of the test, and am therefore the more convinced that this investigation will command attention and repay careful study. It happened that, when the great work of which this forms a part was in contemplation, I was employed to spend some time in Chicago representing the proposing builders of an orthodox, but, as it turned out, greatly superior design of pumps, before the commissioners, and thus was made somewhat familiar with the conditions and requirements, and while, as we naturally concluded, competition in cost rather than in reliability and efficiency resulted in our defeat, I brought away a strong impression of the magnitude and of the importance of this great sanitary work. The pump experiments are interesting, but they simply confirm earlier investigations of the general method of variation of efficiencies with variations of speed of pump, and the maximum attained is good. The conditions were very favorable to the employment of that class of apparatus. The figures here given for efficiency of the two forms of pumps in use, at this time, further illustrate the dominance of the amateur over the expert designer in so many cases in the public works departments of our municipalities.

The working up of the data obtained on the final tests of the machinery here described, was a formidable and tedious and nice piece of work.

The opportunities for test of weirs of large section and great flow have been very few, and such experiments as these have remarkable interest and value both for their rarity and for the importance of the case. The fact, should this evidence be fully corroborated, that the Weisbach formula is the best available for such large work is one which has extreme importance for all such work as is here illustrated. The assurance is the more welcome as the Weisbach formula is a comparatively simple expression and its use is attended with relatively little labor.

The laboratory tests of notches seem to me valuable. They are certainly ingenious.

Mr. Samuel McElroy.—This admirably written paper joins the class of experimental contributions to hydraulic science which merits the thanks of all hydraulic engineers, and the conclusions demonstrated by observations so well conducted are valuable.

Science in various ways has been greatly benefited by laboratory experiments which define principles, but great forces in nature, as engineers meet them, in such a country as ours, often seriously modify laboratory conclusions. We need, then, on the largest scale possible, carefully studied records of observations, which, like this Chicago test, give us additional facts.

One of the valuable points made here is the demonstration of the principle that large sections have less friction than smaller ones, with greater coefficients of discharge. In 1862 Mr. Slade and I claimed, in the Washington aqueduct arbitration, that about 45 per cent. should be added to the standard formulæ of that date for that structure, and actual proof of our position was given. Experiments continued in the same line have confirmed this theory, so that now the coefficient for a "mean hydraulic radius" of 1 being 119.28, in the Chezy formula a "radius" of 4 has 134.42.

It is therefore quite in line that a weir 29.87 feet long should have a coefficient of 3.53, where for 10 feet the elaborate experiments of Mr. Francis had a range of 3.218 to 3.357. There are various reasons why this should be so, one of the most prominent being the superior velocity of the central current in a wider and deeper stream.

It also takes no small laboratory incubus from the conditions of wier flow, attributed to Mr. Francis, to be reminded here how admirably D'Aubuisson demonstrated the weir formula as identical with that of the orifice.

There has been also a great deal of unnecessary prominence given to "end contraction" on a weir, in any stream of important flow, due to the niceties of Mr. Francis' experimental precautions. In ordinary practice, where a weir must usually be narrower than the stream, and where there is the usual velocity of approach, it will be found that, instead of a contraction reducing the practical length of the weir, the water actually piles up as it passes over, and requires a correction increasing the length.

Another point comes directly within the analysis of plain dynamic principles, and, where the forces are at all important, seems much underrated; this is the correction for "velocity of approach."

It is a plain principle in dynamics that the junction of two forces in the same direction gives their sum as the resultant.

It is a plain principle in hydraulics that the flow of any conduit is the product of its mean velocity into its cross-section. If then, by any process, this velocity is increased, there must be a corresponding increase in discharge. Where it takes one foot head to produce a velocity of 8.03 feet a second, slight velocities have little effect, whereas important velocities must not be neglected.

To avoid discussion, I will cite in illustration a single case:

In April, 1869, the North Branch reservoir, 42 miles and 1,015 feet above Lyon's Falls, on the Black River, New York, ruptured its dam in a flood, and in about nine hours poured about 500,000,000 cubic feet over a dam 505 feet long, the crest height being 7.8 feet, when the flow was about 57.745 cubic feet a second. The ordinary formula, without correction, would be $2 = 3\frac{1}{3} \times 505 \times 7.8^{\frac{3}{2}} = 36.336$ cubic feet; while the head should be 10.425 feet, showing practically 2.625 above the actual crest, or about Weisbach's coefficient of 80 per cent. of the head, 3.34 feet, due to the actual 14.66 feet velocity of approach. In other words, less the proper coefficient of friction flow, the whole velocity of approach was an addition to the parabola velocity of the actual weir depth.

Engineers who have to deal with cases like this find it necessary to give subordinate values to laboratory experiments.

Mr. Wm. Kent.—I think Professor Carpenter is to be congratulated on having presented such an admirable paper. I would suggest, if it be possible, that he add a footnote, giving a little of the history of this famous Bridgeport pumping engine.

It is not right that that engine should be allowed to pass into oblivion with so little notice as it has had. Some years hence people going through our transactions will find this wonderful pumping engine, and will want to know something more about it. If it could be recorded what engineers approved and recommended it to the Chicago City Council, and how the Chicago City Council failed to consult a Board of Engineers, who would have told them not to use that engine, it would be an interesting historical statement. It would be of national benefit, I think, if that historical statement could be made and given to city councils in other cities to show them what low economies they were likely to make if they did not call in boards of engineers to give them advice in regard to pumping engines.

I would like also to ask Professor Thurston if he can tell us the limits beyond which we could use the Weisbach formula, and where the Francis formula ceases to be useful.

Mr. H. H. Suplee.—In connection with this subject of the calibration of weirs I should like to call the attention of the members to the very complete experiments made in France at Dijon by M. Bazin, because they explain to a large extent the discrepancies which appear in weir tests. He found that the coefficient depended to a large extent upon the freedom with which the air was allowed to flow in behind the fall of water. In other words, if end boards were used to keep a parallel flow and were carried down so as to close the ends, preventing free access of air behind the fall, the coefficient was materially changed; but that when there was free access of air the experiments gave very uniform results, and constant coefficients were obtained. He experimented on quite a large scale, and his paper has been translated by Mr. Trautwine, and is to be found in the transactions of the Engineers' Club of Philadelphia. I think he uses the Francis formula; I am not quite certain. But he made a number of tests, and a large number of coefficients were determined, and he found that he could vary them very materially by simply offering the freedom of access. There is a suction which tends to draw air in behind the fall. Those who have been at Niagara Falls know what suction there is behind the fall there, and the same thing occurs to a greater or less extent in weir tests, and very materially affects the results.

Mr. Kent.—Did not Francis point that out too?

Mr. Suplee.—To some extent, I believe.

Professor Thurston.—I should, myself, use the Weisbach formula from the limit zero, up, because if it is correct in large values it cannot be very far wrong, I am sure, with small.

*Prof. R. C. Carpenter.**—In reply to the request of Mr. William Kent, the author would state that the following facts in relation to the "Undulating" pump were kindly furnished by John Ericson, City Engineer:

"The pumps were contracted July 8, 1892, the work to be completed by July 9, 1893, at a cost of $24,931 per set of two pumps. The engineer for the contractors was Henry Walsh; the official name of the contractors was the Courtright Machinery Company, with works at South Haven, Michigan. The contract called for four sets of Courtright Undulating Sewerage Pumps with a capacity, when engine was running 100 revolutions per minute at 90 pounds steam pressure, of 25,000 cubic feet per minute against a 6-foot head per set of two pumps, or 20,000 cubic feet per minute against an 8-foot head. Pumps and engine were to pump quantity as stated, and contractors were to keep them in prime condition (repairs on account of ordinary wear and tear excepted) for a period of twelve months after final acceptance. The test of July, 1893, the results of which are given in the paper, prove the pumps unsatisfactory in all respects, making it necessary to take them out and replace the old ones in the latter part of 1893."

In the settlement of the dispute connected with the failure to meet contract requirements, the author was informed that the contractor claimed that his failure to obtain the guaranteed capacity was largely due to the fact that the engine made only 41.4 revolutions per minute instead of 100, as required by the contract, entirely overlooking the fact that this low speed was due to the overloaded condition of the engine. The test shows an efficiency of about 13 per cent. less than obtained at best speed with the centrifugal pump; this serves to show the impossibility of securing the required power from the engine in the station to run the pair of "Undulating" pumps at 100 revolutions, since it was barely able to move the pair of centrifugal pumps at that speed.

There seems to be little evidence as to the methods brought to bear upon the Chicago City Council in 1892 to obtain a contract,

* Author's closure, under the Rules.

but it is quite probable that, had it not been for a change in city administration and city officials between the time of letting the contract and the completion, the mistake might have been greater and all the centrifugal pumps at the Bridgeport Station replaced by the "Undulating" or Courtright pump.

During the time of the test the pumps were running irregularly and only at part capacity, and Chicago River became so foul in consequence as to excite considerable attention from the residents and newspapers. The steamboat lines having their docks near the mouth of the river complained bitterly of loss of business because of the unbearable stench, and threats were made that an injunction would be obtained restraining the construction of the weir and the completion of the test. For these various reasons the construction of the weir was rapidly pushed to completion and the test continued night and day until finished. The weir was then blown out of place by dynamite, and the pumps in the station started at full capacity. This partial stoppage of the sewage pumping station indicates the vital importance of the station to the health of the city.

In relation to the discussion by Mr. S. McElroy, the author would say that the writer is under obligations for the concurrent facts which are given and which tend to establish the fact that long weirs have greater coefficients of flow than short ones. This is doubtless due to the increased strength of the central current, and this, in turn, is probably due to the greater suction at the centre of the weir. In a long weir all the air beneath the overfall must enter at the ends, and although in the weir in question the end space was of no little magnitude, yet it is quite possible that the atmospheric pressure directly beneath the centre of the overflow may have been sufficiently less than that at the ends to make a virtual increase in the head at the centre.

DCCLXIV.*

REDUCTION IN COST OF STEAM POWER FROM 1870 TO 1897.

BY F. W. DEAN, BOSTON, MASS.

(Member of the Society.)

IN the year 1870 the most economical steam engine in use in mills was the Corliss simple condensing engine, which used nineteen or twenty pounds of steam per horse-power per hour. Previous to that time compound engines had been used in England in mill practice, and simple engines had in many cases been changed to compound. In this country compound pumping engines had been used to a very limited extent, notably the Worthington direct-acting tandem duplex compound, the first one of which was put in at the Charlestown, Mass., water works in 1863, and the installation of the Morris engine at Lowell and the Leavitt engine at Lynn are well-known examples of them in the early part of the period which we are considering. The Lowell engine was of the Simpson type, so named from the Simpsons, of London, who originated the arrangement of two compound cylinders with different lengths of strokes under one end of a beam. It is known as the Morris engine from Henry G. Morris, the builder, but its design is due to the late Robert Briggs, of Philadelphia.

The Pawtucket pumping engine, built by George H. Corliss, and started on June 30, 1878, is another important example of economical pumping engines, and probably was the most economical steam engine which had been built up to that time, having used less than 14 pounds of dry steam per indicated horse-power per hour.

While these engines are not mill engines, they influenced the practice of builders of mill engines, and can properly be considered with them. Pumping engines have heretofore been the

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

leaders in economy, but at present the best pumping and mill engines are practically equally economical.

Of course, the greatest single step in economy was the introduction of the compound engine.

At the present time we may cite the Louisville pumping engine and several mill engines, one or more at Grosvenor Dale, Conn.; Natick, R. I.; West Boylston, Mass.; Berkley, R. I., and Lawrence, Mass., as being about on a par, and representing the best commercial economy.

In 1873 the most economical compound engines used about 16½ pounds of steam per indicated horse-power per hour, as shown by tests of the Lynn and Lawrence pumping engines, which then established new records for duty. Improvements in methods of using steam were made until it is now as easy to design an engine to use less than 13 pounds of feed water per horse-power per hour as it was to use as little as 16 pounds in 1875.

At this date steam jackets were common, and were used in all engines which gave the most economical performances. The steps, however, that lowered the steam consumption of compound engines from 16 pounds to 14 pounds per indicated horse-power per hour were largely the introduction of a cut-off on the low-pressure cylinder and a reheating receiver between the cylinders. Although the reheater was invented by the late E. A. Cowper, of London, in 1862, so far as I know, it was first used in this country by E. D. Leavitt in his engines for the Calumet & Hecla Mining Co., and is regarded by him as one of the most important causes of the economy of his engines.

These features appear to have been the principal means of lowering economy to 14 pounds of steam; but to what are we to attribute the step to 13 pounds? Clearance is well known to be an important factor, and its reduction, especially in the last cylinder of a series, is important for economy. It is receiving constant attention from careful designers, and its reduction is a constant source of gain.

The 13-pound mark has also been reached by an increase in steam pressure with resulting increase in the number of expansions. In some cases a reduction in the size of the high-pressure cylinder has doubtless contributed toward economy, by means of which smaller surfaces are exposed to the boiler steam than would otherwise be the ease. This carries with it a pro-

portional reduction of initial condensation in the cylinder which is most prolific in this cause of waste.

Still further, the 13-pound mark has, in general, been attained by engines which have a low-pressure cylinder larger for the work to be done than is commonly the case, so that the mean effective pressure referred to the low-pressure cylinder is in the vicinity of 21 pounds. There are occasional exceptions, as in the case of the Louisville engine, which worked with a mean effective pressure referred to the low-pressure cylinder of 25 pounds. Such cases are exceptional, and their economy can be attributed to great perfection of detail.

It will in general be observed, however, whatever may be said of other causes, that most of the extreme cases of economy are those in which a good vacuum has been maintained. This leads me to say that the importance of good vacuums is often not appreciated, and that air pumps and condensers are as often too small.

There is a strong tendency nowadays to underrate steam jackets, but I believe that in every case where they have been wasteful, or where their economy is indifferent, at all events with ordinary speeds, an examination would show that the jackets are air-bound, water-logged, blowing through traps, or that the jacket piping is bare, and thus steam for heating the building is charged to the engine. Such an arrangement of pipes can furnish but indifferent material for giving up latent heat to the working fluid within the cylinders, and is, in fact, absurd.

The effect of reheaters in drying out steam which issues from a preceding cylinder and in superheating it to 60 degrees or 90 degrees, as is often the case, for use in the next cylinder, cannot be otherwise than advantageous, for, as Professor Thurston shows in his paper of 1894 before this Society, heat so added to the working fluid saves much more steam than was condensed to liberate this heat.

While these considerations are very general, they are necessarily so, for nobody can attribute to any one of the features named its proper effect. Moreover, their combinations are very varied.

Whatever may be said pro and con on this subject, it cannot be denied that the best results have been obtained from engines equipped with jackets and reheaters.

Considering economies effected, it is safe to say that, without including triple-expansion engines, steam economy has steadily

decreased from 20 pounds to $12\frac{1}{2}$ pounds per indicated horse-power between 1870 and 1897. This corresponds to a saving of $\frac{20-12\frac{1}{2}}{20} = 37\frac{1}{2}$ per cent.

Within this period of twenty-seven years the use of exhaust steam has extended in various mills, such as cotton, woollen, and paper mills, so that in some mills the cost of steam power is next to nothing.

Economies of this kind are not confined to the use of the exhaust of non-condensing engines, for since 1895 the writer's firm has had installed at the Washington Mills, Lawrence, Mass., a large surface-condensing vertical compound engine, the rejected heat of which is utilized. In this mill large quantities of warm water are used in the dye-house, which has heretofore been heated by exhaust and direct steam. Now the circulating water of the new engine is sent from the condenser to the dye-house by the circulating pump at about the temperature required. In this case the rejected heat of the engine is just as effectively used up as it would be if the engine were non-condensing and sending its exhaust to the dye-house. There are advantages, moreover, in the compound surface-condensing engine, for there is less rejected heat to use, with consequent diminished chance for waste, and there is less heat lost by radiation from a pipe full of warm water than from one full of steam. This constitutes one of the latest forms of recent economies. It may be mentioned incidentally that by the surface-condensing engine, oil is kept out of the dye-house and away from the cloth. The air-pump discharge, being small in volume, and containing all of the cylinder oil, can be easily taken care of in any way which appears to be advantageous.

What is there to be said concerning boilers within the period that we are considering?

The horizontal return tubular boiler is still the standard * of the country, and will probably so remain. It is cheap, and, if properly built, it is safe. As its tube-heating surface can be effectively blown with steam with the certainty that the jet will strike every part thereof, and as, furthermore, its tubes can be effectively scraped at any time without taking the boiler out of service, it must necessarily be more economical than any of the

* By "standard" is meant the favorite and most commonly employed boiler.

numerous water-tube boilers which are now being introduced. The fire surfaces of the latter can only be indifferently blown, and they cannot be scraped at all unless the boiler is cooled down, and in general it cannot then be done with anything approaching thoroughness.

There is scarcely any improvement to be noted in the horizontal return tubular boiler during the last twenty-seven years as far as economy is concerned, but I believe that grates have been improved to a measurable extent, resulting in an economy of perhaps 2 per cent.

My own experience teaches me that the internally fired boiler, either of the locomotive or vertical type, will save under equal conditions some 7 per cent. of coal compared with the horizontal return tubular boiler, besides causing an important economy in doing away with brickwork.

Mr. Bryan Donkin, in a recent paper before the Institution of Civil Engineers, in discussing boiler economies, says: "Generally speaking, internally fired boilers give a higher efficiency than those externally fired. The old and well-known locomotive type, with smoke tubes and induced draught, stands high as a very economical steam generator." Such praise from so careful an investigator as Mr. Donkin should carry great weight.

Within twenty-seven years economizers for heating feed water in smoke flues have become common. Although subject to a rather large depreciation, in the general case they will save about 7 or 8 per cent. of coal.

There are economies to be obtained from the use of vertical engines. These come from reduction of friction, reduction of repairs to cylinders and pistons, and diminished cylinder oil consumption. It would not surprise me if there were a net saving of 5 per cent. by reduced friction of a vertical compound compared with a horizontal engine.

Summing up the various items that have been mentioned, the following may be presented as the economies of the period from 1870 to 1897:

Saving due to compounding, jackets, reheaters, higher pressures, and greater expansions	37 per cent.
Due to vertical engines	5 " "
Due to vertical internally fired boilers	7 " "
Due to economizers	7 " "
Due to improved grates	2 " "

As these economies could not be simultaneously applied to the original condition of a mill, their sum is not a result which could have been realized in any case.

With these important economies having been brought about during twenty-seven years, the question arises, Are there any compensating disadvantages?

It is easy to show that there are not, for—

First. The first cost of a cross compound condensing engine is no greater than that of a pair of simple condensing engines twenty-seven years ago, on account of improved tools and processes and reduced prices of materials.

Second. Interest charges are less than they were twenty-seven years ago.

Third. The depreciation of engines is less than it was twenty-seven years ago, on account of better materials, better workmanship, better oil, and better means of applying oil. Vertical engines will render the depreciation of cylinders, pistons, piston rods, piston-rod packing, and crossheads less than similar parts in horizontal engines.

Fourth. The reduction in the number of boilers required by some 33 per cent. for a given power within twenty-seven years carries with it many reduced charges, such as first cost, interest, repairs, depreciation, insurance, taxes, cost of boiler-houses, cost of attendance, and various lesser items.

Fifth. Present boiler-building practice is superior to the old, so that high pressures are now as safely and comfortably carried as the lower pressures of 1870. Better materials, longer plates, and fewer joints, butt joints of high efficiency and maintaining the circular form with changes in pressure, drilled holes, hydraulic riveting, and round-tool caulking render it as safe to carry 200 pounds or more as any lower pressure.

Sixth. I might include reductions in cost due to handling coal by conveyers for large plants and by mechanical stokers. Conveyers are in some cases very economical, but mechanical stokers are of doubtful value, speaking generally. The greatest efficiency of the conveyer is to be found in connection with the mechanical stoker.

So far the only steam engine considered is the compound engine. This engine has recently been found capable of utilizing the higher pressures much more economically than was formerly suspected. It has therefore diminished the advantage of

the triple-expansion engine to such an extent that the latter has met with something of a setback. I believe, however, that the triple engine is still to be common when pressures begin to exceed 160 pounds of steam, and its undoubted advantage at sea gives evidence that it will be no less on land. Within a year or two an interesting and instructive comparison can be made between two pumping engines, one compound and one triple, both to use 185 pounds of steam and designed on the same lines by Mr. Leavitt.

It seems probable that the relative economies of the compound engine, using 160 pounds, and the triple, using 185 pounds of steam, are to-day represented in the very best practice by $12\frac{1}{4}$ pounds of steam and $11\frac{1}{4}$ pounds of steam respectively per indicated horse-power per hour. This corresponds to a saving of $\frac{12\frac{1}{4}-11\frac{1}{4}}{12\frac{1}{4}}=8.16$ per cent., which is a paying saving.

Very careful attention should be paid to the kind and condition of steam valves used in engine cylinders, for leaky valves can readily nullify the advantage which may be derived by anything which can be done to contribute to economy in the general design.

The future, so far as we can now see, offers us highly superheated steam for further means of economy. The technical papers have frequent accounts of the use of such steam in Germany, and published tests (See *Engineering*, pp. 113, 391, 1895) show that a small Schmidt "motor" has used 10.17 pounds of steam per indicated horse-power per hour. It would seem that we have a right to anticipate in the early future a steam rate of 10 pounds by means of superheated steam in the best designed engines. Compared with the lowest rate thus far mentioned, this corresponds to a saving of $\frac{11\frac{1}{4}-10}{11\frac{1}{4}}=11.11$ per cent.

We have also in anticipation the use of very high steam pressure and quadruple-expansion engines as built experimentally at Cornell University and described by Professor Thurston last year before this Society. If, however, steam can be so highly superheated that expansion in one cylinder will not cause condensation, nor even the saturated condition until the time of exhaust, as was the case in the Schmidt motor, extreme economy may be obtained without resort to the multiple-expansion engine.

The economies thus far mentioned relate to improvements in engines and boilers ; but one of the greatest economies results from the low cost of coal at present in Lowell, Lawrence, and similarly located towns.

The prices of coal in these places every five years were as follows :

Year.	Price.	Kind of Coal.
1870	$7.10	Anthracite.
1875	7.20	"
1880	4.75	Bituminous.
1885	4.25	"
1890	4.65	"
1895	3.85	"

These prices show a saving from 1870 to 1895 by themselves of about 46 per cent.

I shall now consider the actual figures making up the cost of a mill steam plant, and its cost of operating, say, of 1,000 horse-power in most mill towns in the State of Massachusetts away from tide-water.

The very best steam plant of this power twenty-seven years ago, including a pair of simple condensing engines using 20 pounds of steam, boilers evaporating 8 pounds of water on total coal used, buildings, chimney, and all accessories, cost $70 an indicated horse-power.

The fixed charges on such a plant were interest at 6 per cent., depreciation at 4 per cent., repairs at 2 per cent., insurance at 1 per cent., or a total of 13 per cent.

13 per cent. of $70 is	$9.10
Coal at 2.50 lbs. per I.H.P. per hour, @ $7.10 a ton, $\frac{2.50 \text{ lbs.} \times 10 \text{ hrs.} \times 308 \text{ days} \times \$7.10}{2,240} =$	24.40
Attendance, boilers $\left\{\begin{array}{l}\text{3 day men @ \$1.50} \\ \text{1 night man at \$1.50}\end{array}\right\}$ $\frac{\$6 \times 308}{1,000} =$	1.85
Attendance, engine $\left\{\begin{array}{l}\text{1 engineer @ \$3.00} \\ \text{1 assistant @ \$2.00}\end{array}\right\}$ $\frac{\$5 \times 308}{1,000} =$	1.54
Oil, waste, and supplies	1.25
	$38.14

The very best plant of 1,000 horse-power can be installed to-day complete, including buildings, chimney, compound engine using 12.5 pounds of steam, boilers evaporating 9 pounds of water on

total coal used, economizers, and all accessories, for \$57 per indicated horse-power.

Such a plant can run on 1.4 pounds of coal per indicated horse-power per hour for total coal consumed.

The fixed charges are interest at 5 per cent., average depreciation $3\frac{1}{2}$ per cent., repairs 2 per cent., insurance and taxes 1 per cent., or a total of $11\frac{1}{2}$ per cent.

$11\frac{1}{2}$ per cent. of \$57 is	\$6.55
Coal at 1.4 lbs. per I.H.P. per hr., @ \$3.85 a ton, $\frac{1.4 \times 10 \times 308 \times \$3.85}{2,240} =$	7.41
Attendance, boilers $\left\{\begin{matrix}\text{2 day men @ \$1.50} \\ \text{1 night man @ \$1.50}\end{matrix}\right\} \frac{\$4.50 \times 308}{1,000} =$	1.39
Attendance, engine $\left\{\begin{matrix}\text{1 engineer @ \$3.50} \\ \text{1 assistant @ \$2.00}\end{matrix}\right\} \frac{\$5.50 \times 308}{1,000} =$	1.69
Oil, waste, and supplies	.80
	\$17.84
Saving in 27 years in first cost, $\frac{\$70 - \$57}{70} =$	18.6 per cent.
Saving in 27 years in operation, $\frac{\$38.14 - \$17.84}{38.14} =$	53 per cent.

On the supposition that superheated steam can reduce the steam consumption to 10 pounds per indicated horse-power per hour, and that the combined efficiency of boilers and economizers is not affected thereby, the cost of installation of 1 horse-power can still be taken at \$57.

The cost of coal per I.H.P. will be: $\frac{1.11 \text{ lbs.} \times 10 \text{ hrs.} \times 308 \text{ ds.} \times \$3.85}{2,240} =$	\$5.88
Other charges will be	10.43
Total	\$16.31

This makes a saving of yearly charges, compared with the best present plant, of $\frac{\$17.84 - \$16.31}{\$17.84} = 8\frac{1}{2}$ per cent.

Some actual costs of a yarn mill in Massachusetts built in 1889 are as follows:

Cost per H.P. of engine (compound)	\$60.50
Total coal burnt per year	2,674 tons.
Average I.H.P. for the year	1,132 I.H.P.
Total coal burnt for power, heating mill, and banking fires, per I.H.P. per hour	1.75 lbs.
During the six months when no heating was done, the coal used per I.H.P. per hour was	1.65 lbs.

The cost of operating a horse-power per year was as follows, assuming $11\frac{1}{2}$ per cent. fixed charges :

Total cost of plant, $66,600, at $11\frac{1}{2}$ per cent	$7,659.00
Coal, 2,674 tons, at $4.75 per ton	12,701.00
Attendance $8.85 a day × 308 days	2,725.80
Oil, waste, and supplies	312.00
Total cost of power	$23,397.80
Average horse-power per year	1,132 I.H.P.
Cost per I.H.P. per year	$20.67
Cost corrected for coal used in heating mill	$20.01

The following figures were given in the *Engineering Record* for March 14, 1896, for the Stevens linen mill, Webster, Mass. The engine is a compound, and was indicated morning and afternoon every working day throughout the year, and the coal is that used for all purposes throughout the year.

	1893.	1894.	1895.
Average I.H.P. for the year,	381	393	396
H.P., hours " " "	1,042,221	893,792	1,076,134
Coal, lbs. " " "	1,831,700	1,493,243	1,775,720
Average coal per I.H.P. per hour, lbs.	1.76	1.67	1.65

In order to place them in the pages of the *Transactions* of the Society, and as illustrating a recent steam-engine performance, I add the results of two trials of a high-class steam engine built within the last year. Considering the steam pressure used, it is the best performance of which I know.

The engine is at the mills of the Atlantic Cotton Mills, Lawrence, Mass., and the trials were made on February 17 and 18, 1897, by the writer.

The engine was built by the McIntosh & Seymour Engine Co., of Auburn, N. Y., and is a vertical cross compound, having its shaft a part of the water-wheel shaft. It is provided with gridiron inlet and exhaust valves on both cylinders, and auxiliary cut-off valves of the same kind on both cylinders. The valves have positive motions throughout, and the points of cut-off are determined on both cylinders by a shaft governor.

The high-pressure cylinder is jacketed throughout by steam of boiler pressure, and there are reheating coils in the receiver, through which live steam of boiler pressure circulates. The low-

pressure cylinder is unjacketed. During both tests the condensations from the jacket and reheater were weighed together on platform scales, the amounts of which are stated below. The temperature of the condensation was determined some 30 feet from the reheater. The boilers supplied steam to nothing but the engine.

A feed-water heater was placed in the low-pressure exhaust pipe near the low-pressure cylinder, and the temperatures of the water, as it entered and left, were taken for the purpose of the information gained thereby, although it had no relation to the contract for the engine. For the same reason the jacket and reheater condensations were determined.

The feed water was weighed on accurate scales by an experienced man.

The indicator springs were tested under steam on the government apparatus at the Brooklyn Navy Yard.

The engine was taken in its every-day working condition, and the results are, so far as I can see, being duplicated in regular operation.

After the trial the diameters of the cylinders, while hot, were measured and the lengths of the strokes determined.

In the table it will be noticed that the temperature of the injection and feed waters is stated as 32 degrees Fahr. While this is unusually low, it was determined by five different high-grade thermometers, all of which gave the same result. As the water in the river and canal, from which these waters came, was covered with ice, its temperature must have been almost exactly 32 degrees.

The following are the leading dimensions of the engine, and the result:

DIMENSIONS OF THE ENGINE.

Diameter of the high-pressure cylinder	24.031 in.
" " " low " "	48.031 "
" " " high " piston rod	5.00 "
" " " low " " "	5.00 "
Ratio of piston areas	4 to 1
Stroke of each piston	48.00 in.
Revolutions per minute	about 100 revs.
Piston speed " "	about 800 ft.

Results of Trials.

		1st Trial.	2d Trial.
1.	Duration	5.079 hrs.	5.583 hrs.
2.	Number of revolutions per minute	100.704 revs.	99.633 revs.

Average Temperatures.

3.	Of external air	37 deg.	42 deg.
4.	" engine room	65 "	65 "
5.	" steam near high-pressure cylinder	359 "	371 "
6.	" " " low " "	312 "	309 "
7.	" jacket and reheater drain	342 "	341 "
8.	" injection water	32 "	32 "
9.	" condenser discharge	56 "	66 "
10.	" feed water before entering heater	32 "	32 "
11.	" " " after leaving "	94 "	101 "

Average Pressures.

12.	Of atmosphere by barometer	14.67 lbs.	14.62 lbs.
13.	" steam at engine by gauge	123.00 "	123.00 "
14.	" " " " absolute	137.67 "	137.62 "
15.	" initial in low-pressure cylinder above atmosphere from indicator diagrams	10.00 "	14.50 "
16.	" initial in the low-pressure cylinder absolute from indicator diagrams	24.67 "	29.12 "
17.	Vacuum by test gauge	28.00 in.	27.10 in.
18.	Mean effective pressure in high-pressure cylinder	33.69 lbs.	43.92 lbs.
19.	" " " " low-pressure "	11.19 "	13.91 "
20.	" " " reduced to low-pressure cylinder	19.61 "	24.89 "

Superheat.

21.	Superheat near high-pressure cylinder	7.5 deg.	20 deg.
22.	" " low " "	74 "	61 "

Powers.

23.	Power developed by high-pressure cylinder	365.2 H. P.	470.6 H. P.
24.	" " " low " "	492.9 "	605.8 "
25.	Total horse-power	858.1 "	1,076.4 "
26.	Per cent. of power developed by high-pressure cylinder	42.5	43.7
27.	Per cent. of power developed by low-pressure cylinder	57.5	56.3

Steam Used by the Engine.

28.	Total weight used by engine, jacket, and reheater	56,271 lbs.	76,662 lbs.
29.	" " " " " " " " per hour	11,167 "	13,731 "
30.	Total weight used by jacket and reheater	5,881 "	7,475 "
31.	" " " " " " " per hour	1,158 "	1,339 "
32.	Per cent. of jacket and reheater steam to total used	10.4	9.8
33.	Actual weight of total steam used per I.H.P. per hour	13.01 lbs.	12.76 lbs.
34.	Do. corrected for superheat	13.05 "	12.87 "

The results on the two days furnish some interesting data in relation to the falling off in economy of a compound engine when it is underloaded. Taking the results of the second test as a standard, the load on the first day is 20 per cent. less, while the steam consumption is but slightly over 1 per cent. more.

SAVING BY THE FEED-WATER HEATER.

The average increase in feed-water temperature caused by the heater, for the two days is 65½ degrees, which, under the present conditions of temperature and steam pressure, is equivalent to a saving in coal of 5.6 per cent.

The following table gives the rate of heat transfer from the steam to the water:

	1st Trial.	2d Trial.
Temperature of water before entering heater	32 deg.	32 deg.
" " " after leaving "	94 "	101 "
Increase in temperature of water	62 "	69 "
Average temperature of water in heater	63 "	66.5 "
Absolute pressure in low-pressure exhaust pipe	0.87 lb.	1.36 lbs.
Corresponding temperatures exhaust pipe	99 deg.	111 deg.
Average difference of temperature between steam and water	36 "	44.5 "
Feed water used per hour	11,167 lbs.	13,731 lbs.
Heating surface of heater in contact with steam	234 sq. ft.	234 sq. ft.
Amount of heat transferred per hour, B.T.U	692,354	947,439
Heat transferred per degree of average difference in temperature per square foot of heating surface per hour, B. T. U	82	91

DISCUSSION.

Prof. R. H. Thurston.—I am greatly interested in this paper, not simply as giving us what is always interesting to the engineer, a history of the evolution of the later forms of engine, but in its comments upon the methods by which the gain noted has been brought about. On these points I would like to say a word and to ask a question.

Speaking of the "reheater," * the writer of the paper states that it is considered by makers "one of the most important causes of economy." It is true, as he further says, that I have shown,

* First employed in this country, I think, by the late H. R. Worthington about 1869.

or tried to show, that reheating which results in moderate superheating should prove economical by saving "much more steam than is condensed" to liberate the heat so applied. But where the reheater does not superheat, there is, at least, some question whether it does not waste heat and steam rather than economize. I have always assumed that the reheater is a good thing to introduce in all high-expansion engines; but my attention has recently been called to the fact that this is not necessarily, and often may not be, true.

I have lately been induced to revise the subject and to reëxamine the records, so far as published, and am beginning to think that these accessories may even do measurable injury to the efficiency of the engine, if not so made and proportioned and connected as to insure superheating. Here are some of the facts:

With light loads, as from 30 per cent. of rated load downward, jacketed receivers may show some advantage, but from 50 per cent. upward, it is decidedly a wasteful arrangement in the cases which I have especially noted.

In a paper on performance of Sibley College experimental engine by Professor Carpenter (*Transactions* A. S. M. E., vol. xvi., pp. 913–961) the tests have shown (p. 928) that jackets of high-pressure cylinder and receiver, at loads of 34 horse-power and over, *increased* steam consumption from 5 to 12½ per cent., according to magnitude of load, where the maximum load was about 100 horse-power, and the proper rating not less than that figure. As the cylinder jacket is known to at least do no harm, the waste must, it would seem, be due to the receiver.

In *Transactions* A. S. M. E., vol. xiv., at p. 383, are Professor Peabody's figures for the engines of the Mass. Inst. Technology, practically duplicates of the Sibley College engines. The increase of consumption of steam seems to be about 2 per cent. with steam in receiver jackets.

In *Transactions* A. S. M. E., vol. xv., in one of my own contributions, is the statement of results of test of a French compound, showing a loss by use of the receiver of from 0.15 to 0.27 pound, per indicated horse-power per hour, on a total consumption of from 13.86 to 14.55 pounds.

The area of reheating surface in standard practice ranges, in compounds, from about 0.10 to 0.05 of a square foot per pound of steam passing through them. It should be greater with compounds than with triple-expansion engines, and greater in the

first than in the second receiver of the latter, on account of smaller temperature in the first receiver.

Here are the results of test of a small experimental engine, lately made to secure some facts bearing on this question :

TESTS ON THE CORLISS CROSS COMPOUND,

SIBLEY COLLEGE, *November* 18, 1897.

Steam Pressure, 120 pounds. Vacuum, 25 inches. Revolutions, 87.

No. of Run.	Condition.	Jacket Water lbs. per hour.			Cond. St. lbs. per hour.	Total St. lbs. per. hour.	I. H. P.	D. H. P.	Steam per I. H. P. per hour.	St. per D. H. P. per hour.
		H. P.	Rec.	L. P.						
I.	Unjacketed	....	....	....	1146	1146	70.64	65.77	16.223	17.425
II.	Receiver Jacketed..	....	134.112	....	1146	1280.112	70.75	65.87	18.093	19.434
III.	H. P. Jacketed.....	72.339	....	....	1077.218	1149.612	70.73	65.85	16.253	17.457
IV.	All Jacketed.......	58.380	120.787	71.801	989.160	1240.128	70.99	66.09	17.469	18.764

ORDER OF ECONOMY :

I.—Unjacketed.. 16.223 lbs.
III.—H. P. Jacketed.................................. 16.253 "
V.—Receiver and L. P. Jacketed...................... 17.450 "
IV.—All Jacketed..................................... 17.469 "
II.—Receiver Jacketed................................ 18.093 "

These comparisons are evidently conclusive for this size and style of engine, not necessarily so for another size or style or proportion. The work was performed, in this case, by experts thoroughly familiar with the engine, as well as with the laboratory methods of exact measurement.

Here are other figures from the same source, obtained at an earlier date, and with a poorer vacuum:

TESTS ON CROSS COMPOUND ENGINE.

SIBLEY COLLEGE, *November* 8, 1897.

Steam Pressure, 120 pounds. Vacuum, 23 inches. Revolutions, 87. q = .98+.

JACKET WATER PER HR. LBS.			Cond. Steam per hr. lbs.	Total Steam per hr. lbs.	D. H. P.	I. H. P.	St. per D. H. P. per hr. lbs.	St. per I. H. P. per hr. lbs.
H. P. Cyl.	Rec.	L. P. Cyl.						
I.—Jacketed throughout.								
62.41	119.44	100.46	1021.26	1303.57	66.16	71.06	19.552	18.203
49.13	92.68	84.30	1034.16	1260.27	67.48	72.48	18.676	17.387
60.85	98.82	91.56	922.50	1173.73	60.78	65.29	19.311	17.979
66.26	82.11	74.29	941.76	1164.42	63.48	68.18	18.343	17.077
60.84	98.80	66.98	902.28	1128.90	62.04	66.64	18.196	16.941
59.16	102.79	93.20	971.40	1226.55	65.87	70.75	18.621	17.336
61.96	107.17	96.45	1037.70	1303.28	71.38	76.67	18.258	16.998
53.62	105.56	84.33	1024.98	1268.49	66.91	70.79	18.958	17.650
				Average				17.460
II.—Receiver and Low-Pressure Cylinder Jacketed.								
....	98.19	82.57	839.28	1020.04	51.04	54.82	19.985	18.606
....	123.63	118.03	990.06	1231.72	60.78	65.29	20.265	18.867
....	126.76	95.49	1015.92	1238.17	63.25	67.94	19.576	18.235
....	116.61	98.75	1013.82	1229.32	62.06	66.66	19.809	18.442
....	118.36	91.56	922.98	1132.90	56.03	60.18	20.219	18.824
				Average				18.319
III.—Receiver only Jacketed.								
....	135.69	....	1127.04	1262.73	64.88	69.69	19.462	18.122
....	153.40	....	1144.02	1297.42	66.18	71.09	19.605	18.252
....	141.68	....	1191.60	1333.28	66.23	71.14	20.131	18.742
				Average				18.372
IV.—Unjacketed.								
....	....	....	997.26	997.26	55.49	59.60	17.972	16.732
....	....	....	1072.98	1072.98	60.96	65.48	17.765	16.539
....	....	...	1181.40	1181.40	66.08	70.98	17.878	16.644
				Average				16.638

Expansions, 15 to 17.
Reynolds-Corliss engine, 9″ and 16″ × 36″.
Best results in previous trials with compound unjacketed throughout, 16.41.
With high-pressure cylinder and receiver jacketed, 18.03.

In this case the engine is small, the external heat-radiating areas large, and the initial condensation large. It does not at all follow that, with larger and better proportioned machines, these deductions may not be entirely reversed, as, indeed, they have actually been in the practice of some of our most successful engineers. We must assume that they have found themselves justified in this practice by experience, and that they have exact determinations of gain upon which to base their conclusions and by which to justify their use of the reheater. I am just now seeking facts from all sources relating to this matter, and shall be glad to get such as Mr. Dean, and others familiar with such work, can give me.

I, as one particularly interested in this subject, am glad to learn what Mr. Dean considers the characteristic features of later construction and to what he attributes the great gain of the last twenty five or thirty years. I deduce from his paper that, aside from improved constructions, the following contribute: high steam, good vacuum, large expansion ratios, small clearances, dry steam, and, if practicable, superheating, including the use, for the latter purpose, of the reheater and the steam jacket. The question of the jacket is, I think, pretty well threshed out; that of the reheater remains to be studied.

Readers of this paper would, I think, be glad to get further information relative to the utilization of rejected heat and steam, and its influence in reducing the cost of power. It is obvious that, where the rejected heat can be used for other purposes than the production of power, and purposes for which it has equal value, the cost of power becomes simply that of the mechanical equivalent of that portion of the heat which is actually transformed into mechanical energy, or, more correctly stated, the heat equivalent of the power actually derived from the steam. This, in turn, means the reduction of the cost of power to that of the case in which the engine has an efficiency equal to unity. This, again, corresponds, in most instances, to a consumption of not above two and a half pounds of steam per indicated horsepower per hour, and to the reduction of costs of power, net, to from one-fifth to one-eighth, or even, in the simple engine, to one-tenth, often, of the costs with unutilized exhaust. In such cases of complete utilization of the rejected heat, all engine economies, as those of condensation and high steam and expansion ratios, are entirely unimportant and even useless.

Is not the estimate of the gain to be anticipated, as an average, from raising the steam pressure from 160 to 185 pounds, large? Taking it to be the fact that the later engines may be expected to utilize the higher pressures as completely as do the older machines the lower, the promise would be a gain varying about as the difference of the logarithms of the pressures, or, in this case, as between 12.25 pounds at 160 and 11.75 at 185 pounds pressure.

It is suggested that superheating may tend to do away with the multiple-expansion engine. I have no doubt that this is true; but, at very high pressures, such as are apparently coming in the early future, we may, I think, expect the employment of both moderate superheating and multiple-expansion, although superheating is certainly available for displacing this complication of construction, if it can be employed without danger or deterioration of apparatus. Still, at very high pressures, there still remains the difficulty which Watt's first attempts at expansion met—the irregularity of load on the piston; and this may be the consideration then still justifying the use of two or more cylinders in series.

Mr. William Kent.—I wish to express my appreciation of Mr. Dean's paper as being a valuable contribution to the *Transactions*. The discussion, I believe, will add to its value. The paper, so far as it gives new data, is very acceptable; but when the author expresses his own opinions, he is entering on dangerous ground. If any man expresses before this Society his opinion concerning boilers, he is likely to have some fault found with him. He is apt, moreover, to be quoted by some one in words like those in which Mr. Dean refers to Mr. Donkin, where he says: "Such praise from so careful an investigator as Mr. Donkin should carry great weight." Some one hereafter may say: "Such praise of the tubular boiler from so careful an investigator as Mr. Dean should carry great weight." Therefore, I think it well to place on record in the *Transactions* that Mr. Dean's opinion is not the universal opinion. There are other engineers who think that the horizontal tubular boiler is used because it is cheap, and that as soon as people get rich enough to buy other boilers the horizontal tubular boiler will be less of a favorite than it now is. The opinion that there has been no improvement in economy in the horizontal tubular boiler in the last twenty-seven years is probably true, except in that possibly Mr. Dean himself has improved the economy

of the tubular boiler in the one he recently put up at the Washington Mills by putting in dampers and deflectors to cause the gases to flow more uniformly through the tubes.

Mr. Dean.—Those boilers have not yet been tested, but if everything goes well, they will be tested very soon.

Mr. Kent.—Mr. Dean says that he believes that the grates have been improved to a measurable extent, resulting in an economy of perhaps 2 per cent. I wish to state that my belief is just the opposite—that grates have not improved to any extent in twenty-seven years.

He says that his experience teaches him that the vertical internally fired boiler "will save under equal conditions some 7 per cent. of coal compared with the horizontal return tubular boiler." I think other people's experience will show exactly the opposite of that; that horizontal tubular boilers are sometimes giving 7 per cent. economy over the internally fired boilers. He says that the economizers will save 7 or 8 per cent. of coal. I think he is probably correct in that. There is usually a greater gain found in England, because the boilers there discharge the heat at greater temperatures.

In regard to the vertical engine he says: "It would not surprise me if there were a net saving of 5 per cent." by reduced friction as compared with the horizontal engine. It would surprise me greatly if there were such a large net saving. Doctors disagree on this point.

I have no criticism to make of the statement in the summary that there is a saving of 37 per cent. due to compounding, jackets, reheaters, higher pressures, and greater expansions. But "due to vertical engines five per cent." I think is entirely too large. "Due to vertical, internally fired boilers 7 per cent." I would reduce to zero, because any type of boiler whatever can be made to give about as good economy as any other type if you proportion it right and have all the conditions right. "Due to economizers 7 per cent." I would let stand; and "Due to improved grates 2 per cent." I would reduce to zero. So that when a man expresses his opinion in regard to boilers in the Society, he is apt to find a difference of opinion.

Mr. R. S. Hale.—On page 310 Mr. Dean speaks of a year's record in which the engines were indicated every morning and afternoon. This method is slightly inaccurate, since the load just after starting and just before stopping is frequently irregular,

and often in a mill some particular machine may be on at, say, from 11 A.M. to 12 P.M. only, so that the cards may not give a fair average. There is a method used in one of the large New England mills which gets over this difficulty and which may be of interest. It is to take a card at 7 A.M. on one day, at 8 A.M. the next day, and one hour later each day until the time comes to begin again in the morning. In this way a set of 300 cards is secured, which fairly represents the average power of the engine during the year.

Mr. James Christie.—The advantage to be derived from reheating in the receiver is still open to question, especially under conditions where the engine is at a considerable distance from the boilers, and the condensation in the reheater has to be wasted instead of being returned to the boilers. Appended (see Fig. 65) are given results obtained from carefully conducted tests on a compound engine, which indicate a loss by the use of a reheating coil, and may be of some interest for other reasons.

The engine is a Greene tandem compound, with the well-known cut-off valve gear on both cylinders. Cylinders, 12 inches and 22 inches diameters; 42 inches stroke, running 115 revolutions per minute, and carrying on the main shaft the armature of a 200-kilowatt electric generator; also a 14-foot flywheel; the total weight supported being about 25 tons. The electric power distribution was of an exceedingly fluctuating character, as indicated by the load diagram, on which the full line indicates I. H. P. delivered by the engine and the dotted line E. H. P. delivered by the generator. The exhaust was discharged into a surface condenser. During the tests indicator cards were taken every five minutes, and readings taken simultaneously from ammeter and voltmeter, also from a recording wattmeter. The condensation from the condenser, from the receiver, and from a heater coil in the receiver were separately weighed. The engine was situated about 300 feet from the boilers, and the condensation from reheater was wasted. The tests were repeated and the general results confirmed; as a consequence the use of the reheater was abandoned. The electrical energy was obtained from three observations.

The readings of ammeter and voltmeter were taken every minute, also every five minutes, corresponding to the moment when indicator cards were taken from the engine; also the records of a wattmeter were kept, and these all agreed in a general result

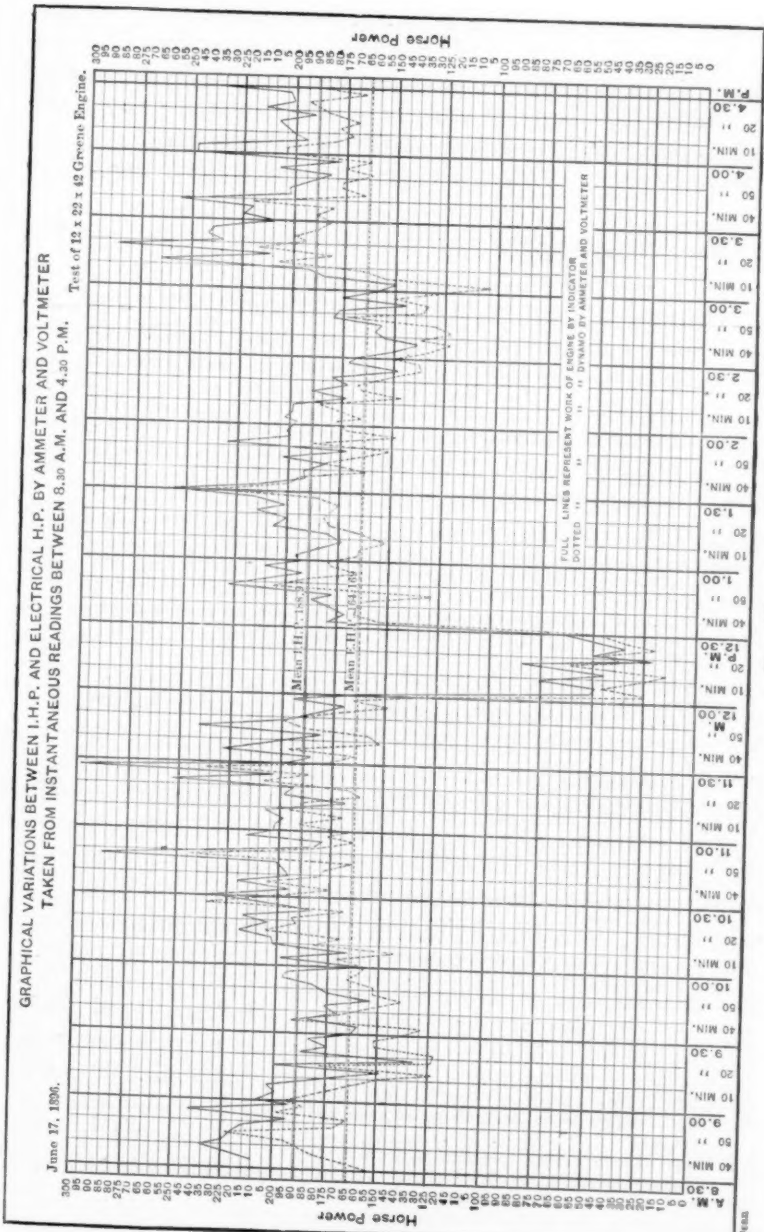
GRAPHICAL VARIATIONS BETWEEN I.H.P. AND ELECTRICAL H.P. BY AMMETER AND VOLTMETER
TAKEN FROM INSTANTANEOUS READINGS BETWEEN 8.30 A.M. AND 4.30 P.M.
June 17, 1896.
Test of 12 x 22 x 42 Greene Engine.
Horse Power
FULL LINES REPRESENT WORK OF ENGINE BY INDICATOR
DOTTED " " DYNAMO BY AMMETER AND VOLTMETER
Am. Bank Note Co. N.Y.
Dean

Fig. 65.

of 86 to 87 per cent. of the indicated horse-power of the engine, the balance being principally absorbed in the friction of the engine, which was considerable, owing to the heavy load borne by the shaft. The large quantity of cooling water, shown in the first column, was passed intentionally for experiment.

Its only practical effect was a reduction in temperature of the

TESTS OF 12 INCH AND 22 INCH BY 42 INCH GREENE ENGINE AND 200 KILOWATT ELECTRIC GENERATOR.

	With Heater Coil.	Without Heater Coil.	
Duration of Test	8	8	hrs.
Average H. P. M. of engine	112.96	115.03	
Average steam pressure	108.60	112.10	lbs.
Average receiver pressure	4.81	5.57	lbs.
Average vacuum in exhaust pipe near engine by gauge	25.0	25.0	inches.
Average vacuum in cylinder by card	20.86	20.68	inches.
Average initial pressure in H. P. cylinder	93.63	104.13	lbs.
Average initial pressure in L. P. cylinder	4.86	5.07	lbs.
Average indicated horse-power	188.91	180.54	
Average ammeter reading (card intervals)	547.20	512.00	amp.
Average voltmeter reading (card intervals)	223.81	226.22	volt.
Average ammeter reading (4,800 observations)	541.90	515.26	amp.
Average watts per hour by 660 ampere wattmeter	123,124	116,249	watts.
H. P. by ammeter and voltmeter (card intervals)	164.169	154.70	
H. P. by ammeter and voltmeter (4,800 observations)	162.58	156.25	
H. P. by wattmeter	165.05	155.83	
Average pounds of cooling water per hour	194,752	98,160	lbs.
Average pounds of condensed steam per hour from condenser	3,562.00	3,317.90	lbs.
Average pounds of condensed steam per hour from receiver	60.50	174.70	lbs.
Average pounds of condensed steam per hour from heater coil	240.10	....	lbs.
Total water used by engine	30,902.311	27,940.50	lbs.
Average temperature of cooling water before entering condenser	74.1	72.5	D. F.
Average temperature of cooling water after leaving condenser	95.9	113.90	D. F.
Average temperature of condensed steam from condenser	80.7	89.40	D. F.
Average pounds of water per I. H. P. per hour	20.45	19.34	lbs.
Efficiency of converting mechanical into electrical energy by observations at card intervals	86.90	85.69	%
Efficiency of converting mechanical into electrical energy by 4,800 observations	86.06	86.54	%
Efficiency of converting mechanical into electrical energy by wattmeter reading	87.37	86.31	%
Ratio of condensed steam to cooling water	54.67 to 1	29.60 to 1	

water condensed from the exhaust steam. As the power delivered by this engine is constantly fluctuating between 100 and 300 horse-power, and the motor service comparable to that of an electric railway, with lines of steep grades, the steam consumption of 19 pounds per horse-power is as high economy as could be expected under the conditions of the service.

Mr. Wm. O. Webber.—I wish to call the attention of the members to the fact that, whereas Mr. Dean's figures as to the cost of steam-power are very interesting and valuable and no doubt absolutely true, his paper must not be misunderstood to say that all steam-power, from no matter what type of engine and size of plant, can be obtained at this same ratio. The figures which Mr. Dean obtains are all of them on large plants approximately about 1,000 horse-power, and while it is undoubtedly true that these low costs can be obtained on engines of the sizes to which he refers, and there has been the large reduction of cost which he states on engines of this type, there has not been the same ratio of saving regarding small plants excepting in so far as the use of cheaper grades of coal are concerned.

I have recently had occasion to figure up the cost of steam-power in a number of small mills and factories using from 100 to 200 horse-power, and find that the figures which I thus obtain check very closely the figures given by Mr. DeCourcy May in the paper submitted to the Society by him some years ago, and which I believe are very accurate.

I would also submit a diagram (Fig. 65*a*) showing three curves plotted by Mr. H. A. Foster, being the results of figures by Mr. Charles E. Emery; my father, Col. Samuel Webber; Mr. R. S. Hale, and Mr. Charles T. Main, showing the charges, operating expenses, and total cost per horse-power for steam plants up to 250 horse-power, which I believe very accurately represents the best modern practice, and from which it can be seen that the total cost of 50 horse-power is given as $100 per horse-power per annum; 100 horse-power at $65; 150 horse-power at $53; 200 horse-power at $47.50; 250 horse-power at $40; 300 horse-power at $37.50; 400 horse-power at $33; 500 horse-power at $30, and where the price of $25 per horse-power, which has been taken as the usual standard in late years, is only reached at 850 horse-power.*

* These figures for costs below 300 horse-power being on simple high-pressure engines running 10 hours per day, 308 days per year, and taking coal at three dollars ($3) per ton.

Some time in the future, when I have a larger collection of thoroughly reliable data, I propose to make a contribution to the Society of a paper giving the relative costs of small steam and water power plants ranging from 50 to 500 horse-power, to show what the actual conditions are, as this point seems to be very largely misunderstood by a great many engineers, so as to controvert the fallacious idea which seems to be accepted, that owing

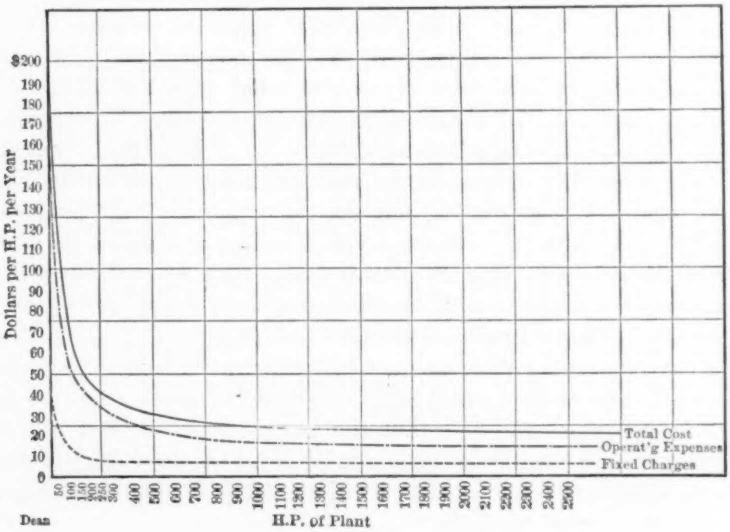

FIG. 65*a*.

to improvements in steam engines in the last few years that all steam-power, no matter of what size, is cheaper than water-power, which I do not believe to be the case.

Mr. Allan Stirling.—The class of papers to which Mr. Dean's belongs is one of the most useful that is contributed to the Society. A prominent specialist submits his experiences and opinions, which, when printed in the *Transactions* with the discussion, are very useful for reference. Especially is this the case when the subject is steam-power, in which every member of this and kindred societies is interested.

It was my privilege to read a paper on this subject at the first meeting of this Society. Messrs. Holley, Worthington, and Hoadley were present at that meeting. We can only look at their portraits now. Their places can never be filled.

In that paper the economy of steam at 300 pounds pressure and high rates of expansion was set forth, and, although we have not reached that point, we are approaching it and realizing to some extent its advantages. Surface condensers on land were recommended, and attention was called to the waste heat in the hot well. It is interesting to note that Mr. Dean's latest plans involve the use of surface condensers and utilizing the heat of the water of condensation.

Mr. Dean advocates the use of vertical engines. The Burden Iron Company, with which I became connected in 1866, have always used vertical Corliss engines, and have never used anything else in their rolling mills.

Superheating the high-pressure steam before entering the first cylinder has not been generally used because of the difficulty of dealing with the combined high pressure and high temperature. Reheating between the cylinders has been proved to be both practical and economical. Probably the best results will be obtained at a pressure of 300 pounds per square inch in a three-cylinder compound, no superheating between boiler and engine, but reheating between cylinders so that the steam at the end of the stroke in the last cylinder will reach the point of saturation.

But it is with boilers that I propose mainly to deal. In 1880 I advocated internally fired square boilers, with the braces grouped for convenient access. Square fire-boxes are now commonly used in locomotives, and Mr. Leavitt uses the square form and grouped braces, but Professor Peabody says that Leavitt's boiler is somewhat complicated in construction and staying, and must be handled with care, especially in starting, to avoid straining from unequal expansion. What Professor Peabody says of Leavitt's boiler is true of all large internally fired boilers, and as it has been proved that they are less economical than externally fired vertical boilers, they have not been much used for stationary work where the conditions permit a choice.

Professor Thurston * estimates that there is sufficient stored energy in a return tubular boiler to project it a mile high, and speaks of the "admitted safety from destructive explosion" of water-tube boilers. Professor Hutton † says: "It is the safety of the sectional type of boilers which has given it its great development in recent years as the pressures of steam have been increasing."

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* Vol. vi., p. 199. † "Power Plants," p. 452.

As generally constructed, return tubular boilers have rivetted joints directly over the fire, and even when the plates are made the whole length of the boiler, there is a rivetted joint in the back connection which is probably the hottest place of all. The flat heads necessitate stays, an element of boiler construction which is dangerous, expensive, and antiquated. The best water-tube boilers are now constructed wholly of curved surfaces in which stays are unnecessary, and the plates with their joints are entirely removed from the action of the fire.

In a return tubular boiler steam is rising from every part, and there is no definite provision for return circulation. This is the reason why it cannot be driven hard, while boilers that have a free and clearly defined circulation can be driven very hard.

Professor Hutton says of the return tubular boiler: "Access to some places is impossible." This is a fatal objection because even good water contains lime salts, which gradually accumulate on the heating surface and must be removed, and access must be had to every part for that purpose. The use of live-steam heaters mitigates this to some extent, but their first cost is high, and they are wasteful of fuel at least to the extent of the radiation of the apparatus, and much time is consumed in removing and replacing the numerous bolts and the joints in the heads, and in removing, cleaning, and replacing the pans. Purifying in reservoirs or tanks is little used owing to high first costs and other considerations. Soft, furry scale collects in all boilers and must be removed by mechanical means. Boiler compounds will not remove it, and it is too tough to be washed off even by a powerful stream of water. The return tubular boiler being inaccessible for this purpose, must be less economical than those water-tube boilers in which access can be easily had to every part of the heating surface. Vertical bent water tubes entering radially into horizontal drums have been found by experience to be far and away the most convenient place to take care of the deposit from any kind of water. There are no stays to prevent ready access, and it has been demonstrated that the furry scale which collects in the tubes near the feed pipe can be cleaned by power apparatus very expeditiously and economically. The hard scale can be loosened by the judicious use of soda, and the loose scale and mud settle to the mud drum, and can either be shovelled or blown out.

Return tubular boilers, in common with fire-tube boilers of

every description, marine, locomotive, or stationary, whether vertical or horizontal, have the great objection that one end of each tube is exposed to the most intense heat of the furnace or combustion chamber. This is one of the principal reasons why naval engineers have discarded the fire tube altogether, and why water-tube boilers are taking the place of fire-tube boilers for all purposes.

Horizontal tubes require a lot of blowing to keep them clear of fire dust and soot, and to do this the boiler must be stopped, the doors opened, and each fire tube blown separately at considerable expense of strength and steam. In a modern water-tube boiler, when the tubes are vertical and in parallel rows, hundreds of tubes can be effectively blown by power apparatus without stopping the boiler and without opening a door, and in about the same time that it takes to blow one tube in a fire-tube boiler.

The inside of fire tubes requires scraping, but the outside of vertical water tubes do not require to be scraped, because they can be reached and thoroughly cleaned by a well-directed jet of high-pressure air or steam.

It is not surprising that many engineers prefer the return tubular boiler, with all its faults, to a form of horizontal water-tube boiler which involves the use of two hand-holes for each tube. Each hand-hole has at least three pieces, and in order to get at boilers of this type for cleaning, these six pieces for each tube must be removed, cleaned, and replaced. Half of these hand-holes are in the back connection, which is the most disagreeable place in which a man can be put to work: his eyes, mouth, nostrils, and ears get filled with soot. It is impossible to tell that the numerous hand-holes are tight until the pressure is applied, and then, if any leaks are found, the water must be let out and the leaks stopped. But the case assumes a very different aspect when the return tubular boiler is compared with the simple form of water-tube boiler, having vertical bent tubes and horizontal drums, in which there are only two manholes to open and close (and no hand-holes) in order to get at every foot of the heating surface for cleaning, and which, in addition to this, possesses the following advantages: No flat surfaces, and therefore no stays, no headers, each tube having its own independent connection at each end to the drums; a mud drum removed from the action of the fire, but warm enough to prevent rusting; a well-defined and thorough circulation; the heating surface consisting only of tubes, and all plates,

with their joints, removed from the action of the fire so that no general explosion can occur; each tube bent to allow for expansion; the heating surface vertical so that flue dust, mud, and loose scale are removed by gravity, and thorough and prompt cleaning of soot and tough scale from every tube by simple power apparatus.

*Mr. Dean.**—Of course I realized when I wrote this paper that I was going to stand up and be knocked down. I have been knocked down on the boiler subject so many times that I am used to it, and I do not mind it very much. As to the value of reheaters, etc., of course I was aware that there are cases in which no saving is produced, and, as everybody knows, a reheater must produce losses in some way. The saving may not, in all cases, counteract those losses. For instance, there is a loss by radiation. This must first be counteracted, after which the gain follows. There are many engines made with reheaters with so little surface that they cannot do any good, and when you use surface enough to superheat from 70 to 90 degrees it seems to me highly probable that there is some good done. I believe that that is the opinion of Professor Thurston.

In regard to the value of improved grates which Mr. Kent has mentioned, of course that is a matter of personal opinion. But I have come to that conclusion.

The statement that the horizontal tubular boiler cannot be forced is one that rather interested me. I will add here that the best result I ever obtained from a horizontal return tubular boiler was when I was getting a horse-power from about eight square feet of heating surface. That was done with only about a quarter of an inch of draft, and with the utmost ease, and the test was duplicated a month later.

Speaking again of what forms on the outside of the tubes of a horizontal tubular boiler, the boiler I speak of as having given these two high results was twenty-four years old, and had the original tubes. The boiler used the water of the Merrimac River, and was located at the Atlantic Cotton Mills, Lawrence, Mass. Of course in the West, where water is bad and all sorts of things get onto the tubes, I could not expect any such results, but in the East, where water is good, practically nothing forms on the outside of the tube.

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* Author's closure, under the Rules.

I am very glad that the paper has brought out a somewhat spirited discussion. That is one function of papers, and this one has realized that end, if no other.

In regard to Mr. Kent's opinion of the relative economies of horizontal return tubular boilers set in brickwork and vertical water-leg boilers, such as the Corliss and Manning, it is evident that Mr. Kent has not tested boilers of these kinds over and over again so as to obtain strictly comparable results. When he does he will find that the efficiency of the horizontal return tubular boiler set in brickwork is about 71 per cent., and the Corliss and Manning about 76 per cent., when the tests are carefully made by the Society's standard method, by the same persons.

I note that Professor Thurston attributes the first use of reheaters in this country to the late Henry R. Worthington in 1869, or thereabout. This is important and interesting.

One speaker at the meeting stated that Mr. Worthington used a compound pumping engine earlier than the Charlestown engine, but the first tandem duplex compound was, I believe, installed at Charlestown, Mass.

DCCLXV.*

BOILER TESTS: CLASSIFICATION OF DATA AND PLOTTED RESULTS.

BY WILLIAM WALLACE CHRISTIE, PATERSON, N. J.

(Member of the Society.)

In a paper recently presented to this Society by Dr. Charles E. Emery † are given diagrams showing the efficiency of heating surface for different boilers, based on "navy" experiments; the Martin vertical tubular type gives the best results. Remarkable conditions were present in obtaining these results, such as one grade of coal and an expert fireman throughout the tests.

Professor Carpenter ‡ gives a diagram plotted from the American edition, Weisbach's *Mechanics*, of some trials made in Philadelphia in 1868, in connection with which are given equations for the mean lines.

Dr. R. H. Thurston § gives the same diagram, introducing slightly different lines and other equations.

Mr. R. S. Hale's paper (dccxvi.) is very full of information and data relative to different rules, etc., regarding the efficiency of heating surface. Along a different line of investigation the writer has collected a large number of tests from various sources, including those by Whitham and Barrus.

These have been tabulated as per tables which follow and the results plotted in diagrams appended.

In the tabulation it will be noticed that the abscissæ are "pounds of coal" in place of "pounds of combustible," as used by Emery and others, because many of the tests do not give combustible per square foot of heating surface.

Table I.—Vertical boilers, using anthracite coal.

Table II.—Vertical boilers, using bituminous coal.

Table III.—Horizontal boilers, using anthracite coal.

Table IV.—Horizontal boilers, using bituminous coal.

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* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

† DCLXXVII., p. 237, vol. xvii.

‡ DCLXXVII., p. 276, vol. xvii.

§ DCCX., p. 160, vol. xviii.

TABLE I.

VERTICAL BOILERS—ANTHRACITE COAL.

(Wm. Wallace Christie, 1897.)

Classification No.	Coal per sq. ft. of Grate per hour.	Coal per sq. ft. of Heat. Sur. per hour.	Water Heat. Sur. sq. ft.	Grate Surface. sq. ft.	Ratio H. S./G. S.	Equivalent Evap per lb. Combustible from and at 212°.	Horse-Power. Rated. 12 ft. H.S. = I.H.P.	Horse-Power. Developed A. S. M. E.
100	8.9	.654	443	32.5	13.6	9.78	37	36.6
101	8.9	.451	443	22.4	19.7	9.79	37	37.5
103	10	.473	5,480	259	21.2	9.26	457	608.6
104	7.5	.283	3,790	143	26.5	8.91	316	242.8
105	11	.368	1,367	45.6	29.9	10.07	114	134.8
106	11.1	.371	1,367	45.6	29.9	9.56	114	128.2
107	17.1	.572	1,367	45.6	29.9	8.18	114	169.8
108	12	.384	1,402	45	31.2	9.17	117	119.8
109	14.2	.455	1,402	45	31.2	8.87	117	137
110	9.8	.308	1,453	45.6	31.8	9.54	121	103.8
111	7.92	.247	1,190	37.12	32	10.66	100	82
112	9.1	.271	205	6.1	33.5	10.51	17	15.5
113	15	.448	205	6.1	33.5	10.22	17	24.5
114	10.9	.306	962	27	35.6	10.36	80	73.9
115	8.2	.224	839	23	36.5	10.00	70	47.2
116	9.66	.259	555	15	37	9.02	47	30.7
117	9.3	.249	840	22.5	37.3	10.61	70	54.8
118	9.3	.243	4,755	157.5	38.2	8.96	400	....
119	12.7	.332	4,755	157.5	38.2	8.43	400	522.5
120	14.3	.374	4,755	157.5	38.2	7.63	400	555.6
121	12.2	.305	5,614	141.7	40	11.44	468	474.4
122	7.19	.178	752	18.62	40.3	10.65	63	35.7
123	11.13	.276	752	18.62	40.3	11.71	63	56.6
124	15.00	.372	752	18.62	40.3	12.47	63	86.6
125	17.8	.441	1,196	28.7	40.3	9.68	100	133.1
126	15.4	.321	761	15.9	47.9	10.13	64	64.3
127	24.1	.503	761	15.9	47.9	9.38	64	91.2
128	14.89	.311	4,100	80	51.25	10.71	342	....
129	20.69	.421	4,100	80	51.25	10.44	342	....
130	12.88	.260	4,100	80	51.25	10.38	342	....
131	22.52	.439	4,100	80	51.25	9.79	342	....
132	20.06	.452	4,100	80	51.25	11.56	342	....
133	22.87	.444	4,100	80	51.25	9.99	342	....
134	15.60	.302	3,100	60	51.66	12.88	260	367.6
135	20.5	.397	3,100	60	51.66	12.14	260	470.8
136	24.5	.474	3,100	60	51.66	12.05	260	580.5

TABLE II.

VERTICAL BOILERS—BITUMINOUS COAL.

(Wm. Wallace Christie, 1897.)

Classification Number.	Coal per sq. ft. of Grate per hour.	Coal per sq. ft. of Heat. Surf. per hour.	Water Heating Surface, sq. ft.	Grate Surface, sq. ft.	Ratio H.S./G.S.	Equiv. Evap. per lb. Comb. from and at 212°	Horse-Power. Rated. 12 ft. H. S. = I.H.P.	Horse-Power. Developed. A. S. M. E.
150	9.9	.318	2,804	90.	31.1	9.16	234	210.3
151	7.3	.230	1,453	45.6	31.8	8.99	120	213.6
152	9.5	.295	2,249	69.7	32.2	9.61	188	155.2
153	18.66	.510	550	15	36.6	11.30	46	93.44
154	10.3	.263	2,536	64.8	39.1	12.29	212	213.2
155	11.61	.290	300	7.33	40	11.86	25	26
156	41.91	1.050	300	7.33	40	9.31	25	67.1
157	60.61	1.515	300	7.33	40	9.80	25	113.8
158	10	248	752	18.62	40.3	11.56	63	67.47
159	19.89	.491	6,669	165	40.5	9.74	556	941
160	7.71	.171	5,250	117	44.8	10.54	438	218
161	16.9	.371	1,638	36	45.5	10.93	137	166.3
162	13.16	.273	1,383	28.7	48.1	13.09	116	123.7
163	23.00	.478	1,383	28.7	48.1	12.00	116	193.6
164	14.7	.305	1,383	28.7	48.1	12.32	116	126.2
165	10.9	.226	1,383	28.7	48.1	12.35	116	95.4
166	10.9	.226	1,383	28.7	48.1	11.61	116	85.93
167	12.30	.255	8,298	172.2	48.1	12.90	692	697
168	13.71	.285	8,298	172.2	48.1	13.09	692	747
169	13.78	.286	8,298	172.2	48.1	12.64	692	759
170	12.72	.264	8,298	172.2	48.1	12.77	692	698
171	10.42	.216	11,064	231.6	48.1	13.40	922	598
172	11.01	.228	9,681	200.9	48.1	13.02	807	613
173	16.3	.337	1,886	38.9	48.4	10.98	157	189.3
174	26	.487	2,028	38	53.3	11.52	169	317.1
175	27.6	.517	2,028	38	53.3	12.06	169	352
176	11.96	.221	7,192	132.8	54.1	10.97	600	460.9
177	25.7	.457	4,960	88.23	56.2	10.77	414	....
178	29.47	.494	2,833	47.50	59.6	10.00	236	188
179	13.1	.217	3,401	56.7	60.2	12.29	284	243.1
180	16.7	.251	3,126	50	62.5	13.01	261	403.3
181	16.8	.252	3,126	50	62.5	10.79	261	243.5
183	26.03	.365	3,126	50	71.2	11.14	261	278.4
184	40.12	.563	2,494	35	71.2	11.71	208	416
185	45.92	.645	2,494	35	71.2	10.85	208	463.5
186	30.4	.410	2,599.4	35	74.2	11.59	217	330.97
187	33.07	.445	2,599.4	35	74.2	11.43	217	353.4
188	35.4	.477	2,599.4	35	74.2	11.06	217	365
189	40.4	.544	2,599.4	35	74.2	10.54	217	399.2

TABLE III.

Horizontal Boilers—Anthracite Coal.

(Wm Wallace Christie, 1897.)

Classification Number.	Coal per sq. ft. of Grate per hour.	Coal per sq. ft. of Heating Surface per hour.	Water Heating Surface, sq. ft.	Grate Surface, sq. ft.	Ratio H. S. / G. S.	Equiv. Evap. per lb. Comb. from and at 212°.	Horse-Power. Rated. 12 ft. H.S. = I. H. P.	Horse-Power. Developed. A. S. M. E.
260	6.1	.813	1,320	175	7.5	9.22	110	240
261	7.4	.986	1,320	175	7.5	8.44	110	272
262	9.7	.890	464	42.7	10.9	7.97	39	82.4
263	10.6	.972	394	36.1	10.9	......	33	62
264	8.62	.359	852.5	36	24	12.12	71	90.88
265	7.9	.300	639	24	26.6	9.87	54	48.1
266	8.5	.287	629	21.2	29.6	10.85	53	92.7
267	11.7	.400	1,733	58.5	29.6	10.63	145	149.2
268	12.9	.440	1,733	58.5	29.6	9.25	145	192.3
269	6	.202	629	21.2	29.7	10.88	53	33.5
270	11.4	.384	629	21.2	29.7	10.46	53	61.4
271	10.9	.335	1,041	32	32.5	11.38	87	178
272	11.4	.350	1,041	32	32.5	11.30	87	188.7
273	11.5	.353	1,041	32	32.5	11.07	87	194.6
274	10.1	.304	644	20	33.2	10.76	53.7	53.9
275	7.25	.216	753.6	22.5	33.5	11.92	63	46.96
276	6.5	.192	669	19.9	33.7	11.06	56	33.9
277	12.1	.359	669	19.9	33.7	10.76	56	62.1
278	9.8	.275	900	26.7	33.8	11.06	75	66.9
279	9.6	.284	900	26.7	33.8	10.72	75	65.8
280	15.24	.446	682.5	20	34.1	8.86	57	......
281	14	.404	890	25.7	34.6	11.24	74	105.5
282	5.7	.160	639	18	35.5	10.48	53	25.5
283	7.7	.213	719	19.9	36.1	10.25	60	79.4
284	10	.270	890	24.1	37	10.75	74	64
285	10.8	.292	890	24.1	37	9.98	74	62.8
286	12.2	.330	890	24.1	37	10.65	74	81.9
287	13.2	.357	890	24.1	37	10.74	74	87.7
288	14.2	.383	890	24.1	37	10.47	74	87.8
289	4.7	.125	736	19.5	37.6	11.01	62	25.1
290	4.7	.125	736	19.5	37.6	11.42	62	27.8
291	8.6	.228	736	19.5	37.6	11.44	62	48.2
292	8.7	.231	736	19.5	37.6	11.63	62	50.3
293	10.66	.283	1,676.3	44.5	37.67	11.82	140	135.59
294	9.76	.257	1,598.4	42	38	12.09	133	119.83
295	11.11	.290	4,569	120	38.3	10.73	381	345
296	16.4	.404	1,706	42	40.6	10.18	142	150.9
297	26.1	.642	1,706	42	40.6	9.03	142	209.4
298	11	.262	1,041	24.7	42	11.13	87	79.5
299	12.2	.290	1,041	24.7	42	11.20	87	88.5
300	15.92	.362	1,317	30	43.9	10.76	110	122.5
301	9.4	.212	1,047	23.7	44.2	10.61	88	58.4
302	22.3	.489	7,524	165	45.6	11.14	627	935.9
303	22.3	.489	7,524	165	45.6	11.45	627	961.4
304	5.93	.127	3,640	78	46.6	11.76	304	124.26
305	11.9	.251	3,306	69.8	47.4	10.60	276	228.7
306	20.14	.414	1,215	25	48.6	10.26	102	132.3
307	12.08	.241	1,960	39	50	10.73	164	121.9
308	14.8	.276	5,144	96	53.6	11.97	429	410.5
309	21.5	.401	5,144	96	53.6	12.02	429	611.8
310	27	.503	5,144	96	53.6	10.46	429	691
311	13.02	.242	2,877	53.5	53.7	11.64	240	215.5
312	13.5	.248	640	11.7	54.4	10.05	54	36.3
313	11.9	.205	3,242	56	57.9	11.33	270	196.1
314	10.3	.171	5,412	90	60	10.78	451	241.5
315	14.5	.237	2,305	36.6	61.1	11.00	192	155.1
316	19.8	.323	4,225	68.9	61.3	11.31	352	370.4
317	28	.456	4,225	68.9	61.3	10.08	352	442.3
318	32.9	.536	4,225	68.9	61.3	11.00	352	581
319	26.3	.423	7,700	124	62.1	11.81	642	901.8
320	31.9	.513	3,850	62	62.1	11.87	321	534
321	21.3	.340	1,253	20	62.6	11.04	105	114
322	30.2	.482	1,253	20	62.6	11.00	105	154.3
323	11.5	.169	2,680	39	68	11.08	224	124.2
324	14.25	.208	6,150	90	68.3	11.11	513	359
325	9.4	.131	1,609	22.5	71.5	10.39	134	55
326	20	.260	688.1	9.2	76.9	9.55	58	45.5
327	33.7	.432	4,360	56	78	11.38	364	500.3
328	32.5	.346	12,675	135	93.9	12.29	1,056	840.4
329	45.4	.483	12,675	135	93.9	11.69	1,056	553.1

TABLE IV.

Horizontal Boilers—Bituminous Coal.

(Wm. Wallace Christie, 1897.)

Classification Number.	Coal per sq. ft. of Grate per hour.	Coal per sq. ft. of Heat. Surf. per hour.	Water Heating Surface sq. ft.	Grate Surface sq. ft.	Ratio $\frac{H.S.}{G.S.}$	Equiv. Evap. per lb. Comb. from and at 212°.	Horse-Power. Rated. 12 ft. H.S. = I. H.P.	Horse-Power. Developed A. S. M. E.
375	7.5	.688	394	36.1	10.9	8.59	33	60.8
376	7.5	.688	394	36.1	10.9	8.74	33	60.8
377	9.52	.426	322	14.4	22.3	9.48	27	34.9
378	23.75	1.055	2,880	128	22.5	9.2	240	....
379	17.3	.668	5,628	217.6	25.9	10	469	341.4
380	21.3	.822	5,628	217.6	25.9	11.06	469	....
381	5.72	.211	820	30.25	27.1	8.95	69	40
382	5.58	.206	820	30.25	27.1	9.67	69	42
383	10.9	.371	3,534	120	29.4	10.60	300	380
384	10	.328	1,235	40.5	30.5	10.91	103	115.1
385	10.8	.354	1,235	40.5	30.5	10.19	103	117.3
386	10.1	.313	644	20	32.2	11.52	54	60
387	12.3	.382	783	24	32.2	10	66	79.7
388	9.1	.280	2,082	64	32.5	11.39	174	171.9
389	18.2	.526	890	25.7	34.6	11.17	74	143.8
390	18.8	.543	890	25.7	34.6	10.34	74	135
391	9.1	.246	890	24.1	37	11.78	74	69.6
392	25	.625	2,038	52	40	9.59	170	....
393	7	.168	3,374	90	41.6	12.07	281	204.1
394	12.2	.293	474	11.38	41.6	11.74	40	43.3
395	13.9	.334	474	11.38	41.6	11.92	40	49.1
396	22.4	.538	9,000	216	41.6	11.29	750	1,347
397	22.5	.541	9,000	216	41.6	9.24	750	1,202
400	14	.333	1,041	24.7	42	11.37	87	105.4
403	11.1	.261	2,100	49.3	42.5	11.98	175	177.6
404	15.18	.356	1,137	26.7	42.6	11.53	100	127.5
405	19.20	.450	1,137	26.7	42.6	11.20	100	150
406	17.45	.409	1,137	26.7	42.6	11.60	100	148.6
407	20.87	.490	1,137	26.7	42.6	11.27	100	169.6
408	19.73	.463	1,137	26.7	42.6	11.53	100	169.1
409	26.55	.623	1,137	26.7	42.6	10.76	100	199.7
410	23.86	.560	1,137	26.7	42.6	11.30	100	197.3
411	30.10	.706	1,137	26.7	42.6	10.29	100	217.4
412	27.32	.641	1,137	26.7	42.6	11.19	100	226.1
413	34.30	.805	1,137	26.7	42.6	9.43	100	239
414	6.49	.152	1,137	26.7	42.6	11.38	100	52.4
415	6.49	.152	1,137	26.7	42.6	11.43	100	52.4
416	8.89	.208	1,137	26.7	42.6	11.38	100	74.6
417	9.33	.219	1,137	26.7	42.6	11.57	100	77.3
418	12.13	.285	1,137	26.7	42.6	11.29	100	97.7

TABLE IV.—*Continued.*

Classification Number.	Coal per sq. ft. of Grate per hour.	Coal per sq. ft. of Heat. Surf. per hour.	Water Heating Surface sq. ft.	Grate Surface sq. ft.	Ratio H.S. / G.S.	Equiv. Evap. per lb. Comb. from and at 212°.	Horse-Power. Rated. 12 ft. H.S. = I. H.P.	Horse-Power. Developed A.S.M.E.
419	12.30	.288	1,137	26.7	42.6	11.56	100	104.2
420	16.35	.384	1,137	26.7	42.6	10.99	100	125.3
421	6.76	.148	1,216	26.65	45.5	10.88	102	55.9
422	13.69	.301	1,708	37.5	45.5	11.00	143	108
423	23.53	.517	2,040	44.8	45.5	10.46	170	304
424	21	.460	903	20	45.68	9.02	74	....
425	21.3	.466	903	20	45.68	9.61	74	....
426	23.1	.505	903	20	45.68	8.85	74	....
427	23.28	.509	903	20	45.68	9.53	74	....
428	25	.547	903	20	45.68	10.12	74	....
429	17	.369	1,150	25	46	11.60	96	143.2
430	36.97	.798	2,758	59.5	46.3	6.29	230	401.2
431	13.2	.281	640	13.5	47	9.91	54	47.2
432	6.7	.141	3,306	69.8	47.4	11.24	276	141.3
433	9.79	.201	3,501	72	48.7	11.64	292	219
434	11.03	.223	3,467	70	49.5	10.24	289	231
435	12.57	.254	3,467	70	49.5	10.51	289	252
436	27.22	.542	1,100	21.87	50.2	10.52	92	161.4
437	18.6	.367	2,852	50	50.6	9.84	238	....
438	13.3	.261	12,480	245.4	50.8	13.33	1,040	1,178
439	13.6	.256	1,262	23.7	53.1	12.47	105	108.1
440	19.3	.355	640	11.7	54.4	10.93	54	65.3
441	23.8	.414	5,516	96	57.5	9.71	460	....
442	41.0	.713	2,300	40	57.5	7.76	184	369.97
443	12.1	.209	3,242	56	57.9	11.99	270	214.6
444	18.58	.308	1,823	30	60.15	11.57	152	....
445	36.42	.605	1,823	30	60.15	7.58	152	....
446	18.4	.303	2,758	45.5	60.6	11.76	230	259.5
447	23.9	.394	2,758	45.5	60.6	12.19	230	348.2
448	7.96	.130	1,221	20	61	11.81	102	50.4
449	21.51	.352	2,875	47	61.1	10.26	240	258
450	33.2	.541	2,789	45.5	61.3	11.90	233	468.8
451	20.83	.337	5,190	84	61.7	13.01	433	....
452	12.5	.206	4,318	70	62	11.78	360	277.8
453	57.20	.892	2,300	36	63.9	7.44	192	420.8
454	9.3	.140	5,292	80	66.1	12.03	441	221.4
455	10.97	.160	6,150	90	68.3	12.42	513	331.8
456	8.2	.114	1,609	225	71.5	10.99	134	55
457	40.5	.528	2,758	36	76.6	6.38	230	277.7

From the above tables the data have been used in plotting the following diagrams, which are self-explanatory:

Diagram	I.—	Vertical boilers,	anthracite	coal.
"	II.—	" "	"	"
"	III.—	" "	bituminous	"
"	IV.—	" "	"	"
"	V.—	Horizontal "	anthracite	"
"	VI.—	" "	"	"
"	VII.—	" "	bituminous	"
"	VIII.—	" "	"	"

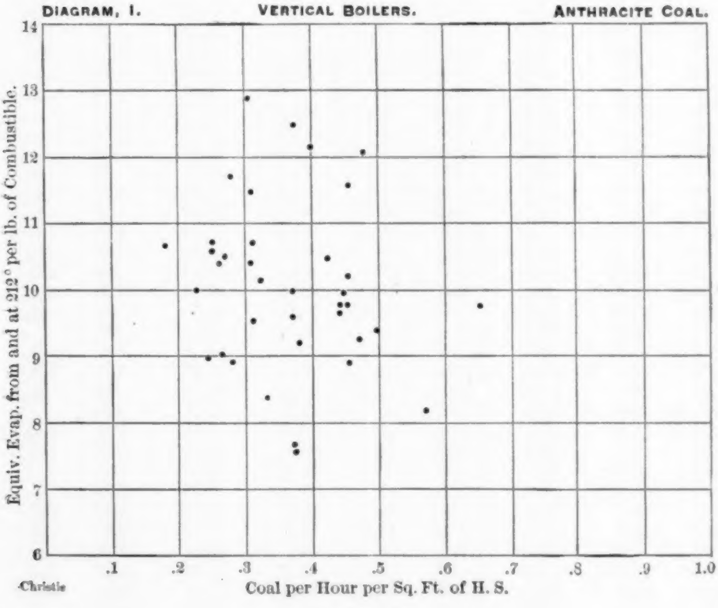


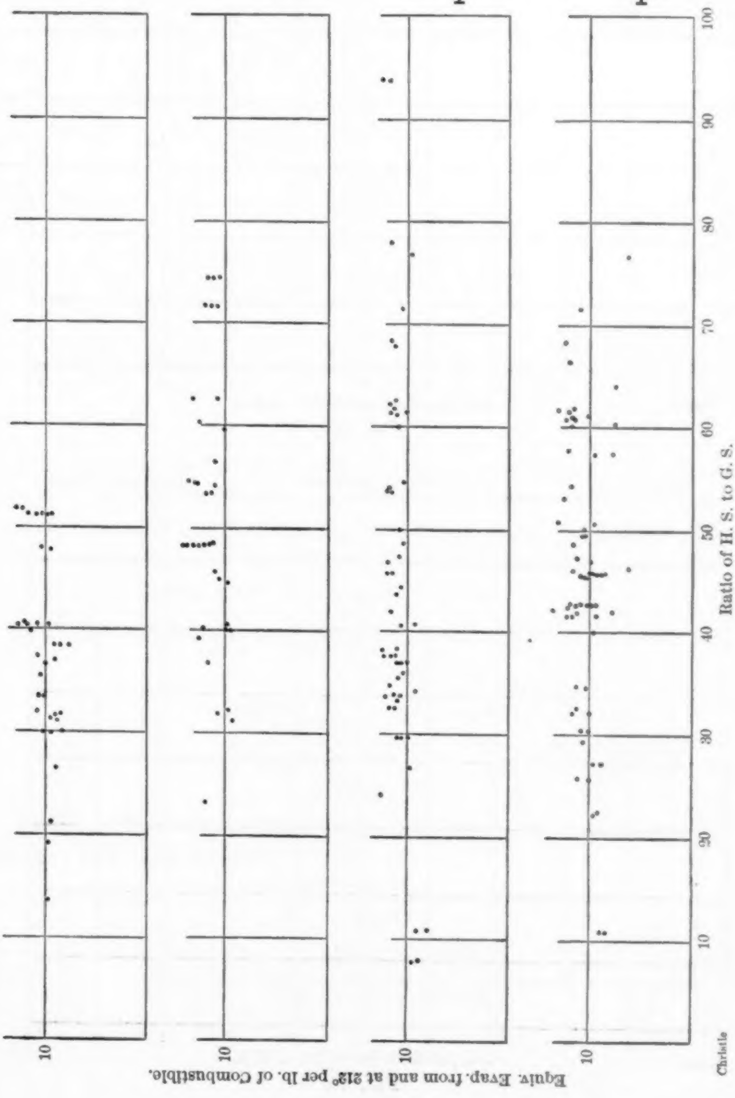
FIG. 66.

DIAGRAM, II.
VERTICAL BOILERS.
ANTHRACITE COAL.
FIG. 67.

DIAGRAM, IV.
VERTICAL BOILERS.
BITUMINOUS COAL.
FIG. 69.

DIAGRAM, VI.
HORIZONTAL BOILERS.
ANTHRACITE COAL.
FIG. 71.

DIAGRAM, VIII.
HORIZONTAL BOILERS.
BITUMINOUS COAL.
FIG. 73.



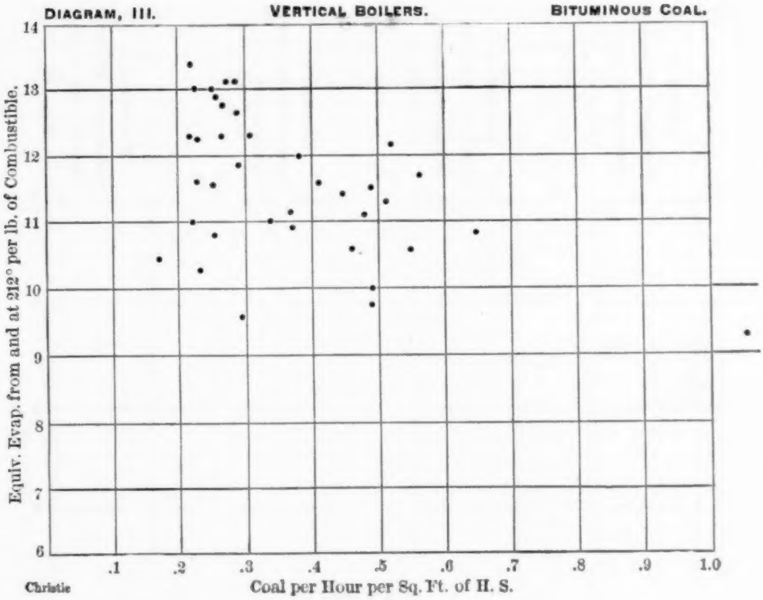

DIAGRAM, III.
VERTICAL BOILERS.
BITUMINOUS COAL.
Equiv. Evap. from and at 212° per lb. of Combustible.
14
13
12
11
10
9
8
7
6
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Christie
Coal per Hour per Sq. Ft. of H. S.

FIG. 68.

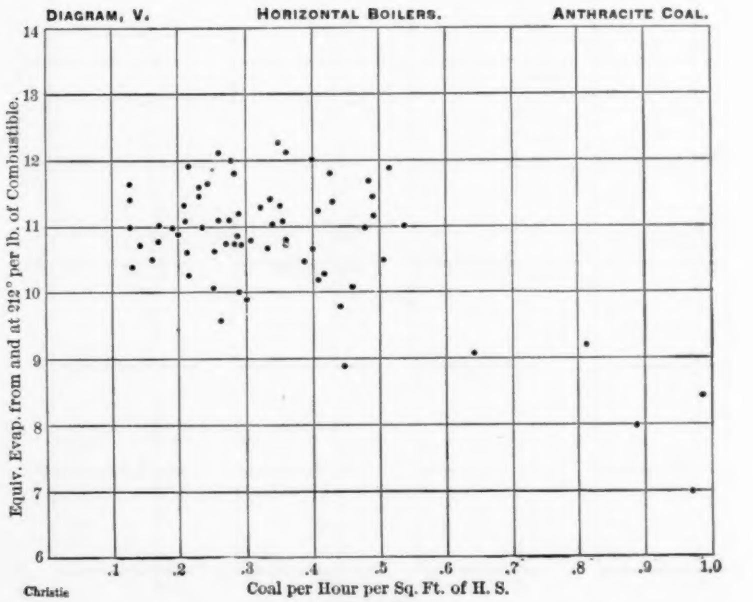

DIAGRAM, V.
HORIZONTAL BOILERS.
ANTHRACITE COAL.
Equiv. Evap. from and at 212° per lb. of Combustible.
14
13
12
11
10
9
8
7
6
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Christie
Coal per Hour per Sq. Ft. of H. S.

FIG. 70.

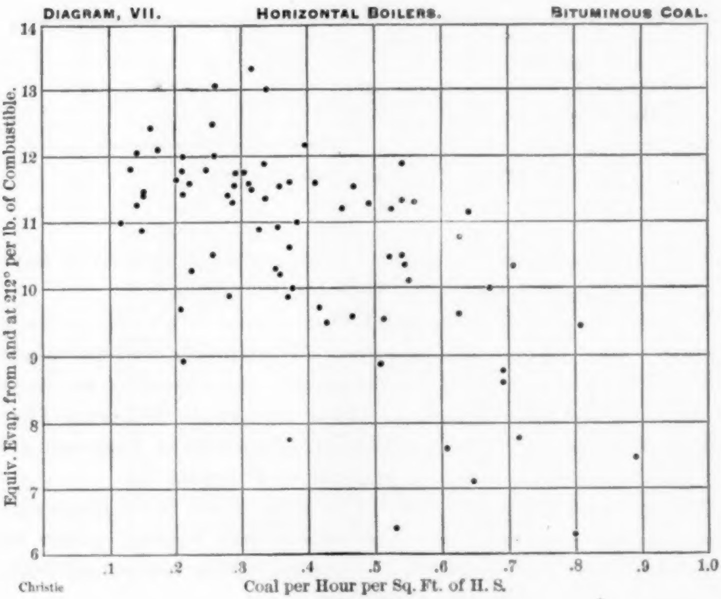


FIG. 72.

The location in the diagrams of most economical performance seems to him to be within a certain area rather than on a particular line, and lower than the line given in some of the above-mentioned diagrams; and the writer has tabulated these areas of most economical performance as follows:

FROM DIAGRAM.	Between Rate of Combustion per sq. ft. of H. S. of	Best at Coal per sq. ft. of H. S.	Best at Ratio of H. S. to G. S. of
I.	0.27 to 0.47	0.3	40 to 52
III.	0.21 to 0.29	0.21	48 to 63
IV.	0.13 to 0.51	0.35	24 to 94
VII.	0.13 to 0.54	0.315	41 to 68

Plotting the above tabulation, we have the following diagrams (XII. and XIII.):

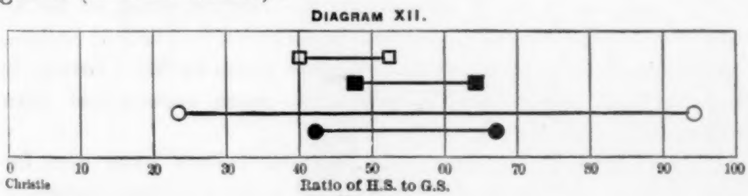


FIG. 77.

DIAGRAM XIII.

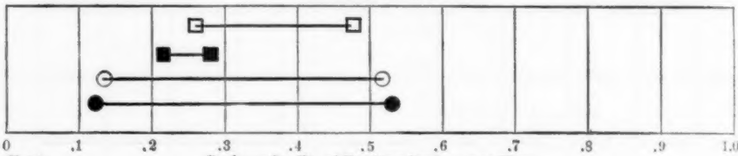


FIG. 78.

In these two diagrams vertical position does not mean anything; arrangement was made thus for convenience.

Plotting the averages obtained from Tables I. to IV., we have Diagrams IX., X., and XI., in which the ordinates are equivalent evaporation per pound of combustible; for abscissæ we have the ratio of heating surface to grate surface in Diagram IX.; coal per hour per square foot of heating surface in Diagram X.; coal per hour per square foot of grate in Diagram XI.

It is interesting to note that in each of these three diagrams the vertical boiler occupies the lowest and highest place as far as evaporative efficiency is concerned, while horizontal boilers occupy the middle positions.

The influence of ratio of heating surface to grate surface, and of coal per hour per square foot of heating surface on evaporative efficiency, may be studied by reference to Diagrams I. to VIII. (Figs. 66 to 73).

NOTE.—Throughout the paper H. S. means water heating surface.

DISCUSSION.

Mr. Allan Stirling.—In this paper Mr. Christie gives anthracite and bituminous coal equal prominence, but tests with anthracite coal are of comparatively little importance, as it is used very little in boilers. I have therefore reproduced the important diagram of Mr. Christie's paper in its relation to the bituminous coal only.

This diagram (Fig. 79) shows that the highest place, so far as evaporative efficiency is concerned, is occupied by vertical boilers. The average result of 121 tests of boilers, given by Mr. Christie, is that vertical boilers are $7\frac{1}{2}$ per cent. more economical than horizontal.

It is easy to find reasons why vertical boilers have won for themselves the highest place. Vertical heating surface naturally

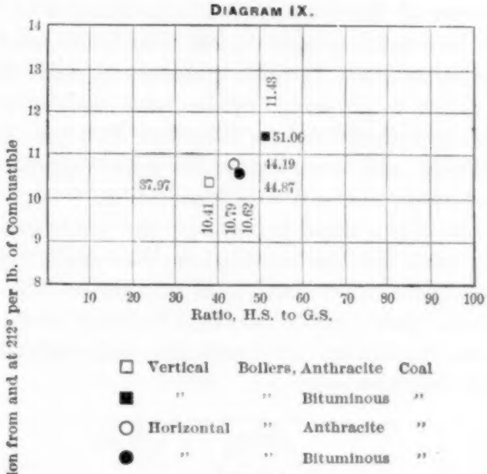


FIG. 74.

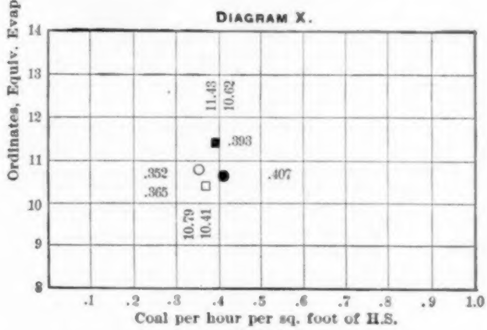


FIG. 75.

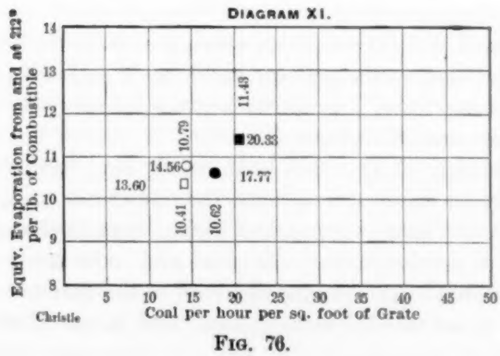


FIG. 76.

rids itself of some of the impurities in the water, and the dust in the fire gases, to a much greater extent than horizontal surface.

It has been stated that the fire gases carry with them out of the furnace about 1 per cent. of the total weight of the coal burned. With horizontal tubes this flue dust can only be removed by blowing and scraping, while with vertical tubes it is regularly removed by the action of gravitation.

Two elements of the deposit made by the water usually fed to boilers are the mud and the hard, glassy-like scale which will be found on the remotest part of the heating surface. The mud will settle; the hard, glassy scale can be loosened by the judicious use of soda, combined with the expansion and contraction of the metal, and will then also settle.

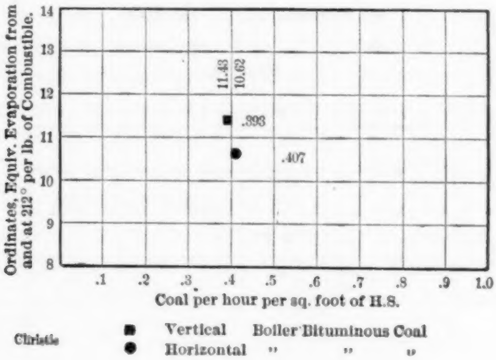


Fig. 79.

The action of a horizontal tube, compared with a vertical one, so far as the foregoing elements are concerned, is illustrated by the following diagram (Fig. 80).

The horizontal fire tube collects much flue dust and some scale. The horizontal water tube collects much scale and some flue dust. The vertical water tube, if properly arranged, gets rid of flue dust, mud, and loose scale by gravity.

As the cleaning of the flue dust, mud, etc., from horizontal tubes can only be done at intervals, the inevitable result is that vertical tubes are more economical of fuel than horizontal tubes.

In vertical fire-tube boilers the mud and loose scale settle on the flat tube plate which forms the roof of the furnace. This is the source of great trouble and expense, and is one of the reasons why the vertical fire-tube boiler has not come into general use.

In vertical water-tube boilers with straight tubes, the flue dust settles on the flat horizontal tube plate, forming the top of the mud drum, and it cannot be removed because it is impossible to get access to it.

Although the vertical surface naturally rids itself of flue dust, mud, and loose scale, there still remain the soot and the tough scale, which adhere to all surfaces, whether vertical or horizontal, and which must be removed by mechanical means.

In a vertical fire-tube boiler, to clean the soot from the tubes necessitates the shutting down of the boiler. The man must get on top of the boiler, and either remove the chimney or get into it, and each tube must be cleaned individually at considerable expense of time and steam. In vertical water-tube boilers, in

Fig. 80.

which the tubes are arranged in circles, it is impossible to brush the soot off the tubes. In vertical water-tube boilers, in which the tubes are arranged in parallel rows, hundreds of tubes can be effectively blown by a simple power apparatus, without opening a door, and in about the same time that it takes to blow one tube in a fire-tube boiler.

When the matter of the tough scale, which adheres even to vertical surfaces, is taken into consideration, it will be seen that the vertical fire-tube boiler is open to the same fatal objection which has been found to horizontal fire-tube boilers, viz.: access to some places is impossible. I was taught the necessity for providing access to every foot of the heating surface for the purpose of cleaning the scale by mechanical means, by a severe experience in Brooklyn, in 1885, with the first water-tube boiler I built. This boiler was not readily accessible for cleaning, and gradually accumulated scale. One night a tube burned out and burst, scalding two men so badly that, although they recovered, their lives were despaired of for a time. This was the only case in which men have been injured by a boiler with which I have been connected. It was a hard and costly lesson, but it

taught me that circulation will not keep a boiler clean even with exceptionally good water, such as Brooklyn had in 1885, and that it is necessary to provide easy access to every foot of the heating surface for the purpose of removing this tough scale, in order that a boiler may be safe, economical, efficient, and durable. There may be an occasional exception, such as the water of the Merrimac River, but I have had no experience with such pure water, and it is rarely met with.

The superiority of vertical over horizontal tubes, and the advantage of convenient access and machine cleaning, were well illustrated by a case in Scotland. A large steel works there gave me an order, in 1894, for a water-tube boiler of 4,370 feet of heating surface, to be installed between rows of Babcocks. The water was very bad, necessitating the stoppage of each Babcock for one day every five weeks for cleaning, and four men were constantly employed cleaning the Babcocks. The large boiler, which I installed, ran far beyond its rated capacity for eighteen months, night and day, without stoppage for cleaning. The mud and the hard, glassy scale were removed regularly by blowing off, by the judicious use of soda, and by washing out with a hose. Although the owners of the boiler wrote me that the tubes near the feed pipe were gradually filling up, I pursued my journeys in Britain and on the Continent, and at the end of eighteen months I cleaned the tubes near the feed pipe in a few hours, and the boiler went to work again for another long period. Some of the tubes in this boiler, which were cleaned without difficulty, had bends amounting to 180° in each. It has been said that scale inside of a bent tube cannot be cleaned, and that boilers constructed of bent tubes have died a natural death and been buried because they could not be cleaned, but the fact is that vertical bent tubes, entering radially into horizontal drums, can be cleaned quicker, by power apparatus, than straight tubes either vertical or horizontal. I have been informed by an eminent member of this Society that in parts of Ohio, where the water is bad, bent tubes, when scaly, are cut out and replaced with new ones. This is unnecessary because vertical bent tubes can be cleaned readily by power apparatus.

I wish here to give a word of caution as to the danger of using water-tube boilers with straight tubes and flat tube plates. It was a boiler of this description, called the Firmenich, which exploded and wrecked a large flour mill, in St. Louis, several years ago. The strains on the tube plates of water-tube boilers are

totally different from those in fire-tube boilers. A little reflection will convince any engineer that flat tube plates in a water-tube boiler, to be safe, must have a stay between each tube, and this is the case in the Heine boiler. Stays in the drums of vertical water-tube boilers make them inaccessible for cleaning; therefore I say avoid flat tube plates in water-tube boilers, as they are very dangerous.

There is still another reason why vertical boilers have won for themselves the highest place. In properly constructed vertical boilers the heating surface is further removed from the fire than in horizontal boilers. This is a very important matter, as the volatile hydrocarbons, which form a large percentage of all bituminous coals, require for their proper combustion that there shall be time and space between the grate and the heating surface.

There are two other matters, in addition to the economy of coal, which should be noted in favor of vertical tubes: 1st, the much smaller cost in cleaning; and, 2d, the saving in interest, depreciation, and repairs from the use of fewer boilers, due to the fact that stoppages for cleaning are shorter and less frequent.

Taking the data which Mr. Dean gives in his paper, read at this meeting, an economy of coal of 7½ per cent., due to vertical boilers, as shown by Mr. Christie's tests, work out at 55 cents per horse-power year. First-class vertical water-tube boilers can be bought and installed complete, to-day, for less than $5 per indicated horse-power, so that it would pay more than 10 per cent per annum to throw out horizontal boilers and substitute vertical water-tube boilers.

Prof. R. C. Carpenter.—In the paper by Mr. Christie is an extensive collection of results of boiler tests, but I cannot but feel that in its present form the data so laboriously collected will be of little value; it could, however, be made of great value by giving additional information in relation to each test regarding kind of fuel, make of boiler, and authority quoted.

It is also regretted that the diagram of results is not plotted with reference to combustible per square foot of grate, especially for the bituminous coal, instead of coal per square foot of grate. It would seem that such data must have been available, or at least could have been found by calculation, since the results are given as evaporation per pound of combustible instead of per pound of coal. The heating value of coal used in different sections of the country varies more than 50 per cent. for an equal

weight, while the variation in heating value per pound of combustible probably does not exceed 10 per cent. For this reason diagrams or results based on combustible are more strictly comparable than when based on coal.

The writer found that a simple empirical equation of the form $y = B - c\sqrt{x}$, in which y = evaporation per pound of combustible, x weight of combustible per hour per square foot of heating surface, B a constant depending on the fuel equal 14.3 for coal, c a constant depending on the form of boiler, etc. The equation seems to have a rational basis for high values of y and low values of x, but fails, and may even give absurd results for extremely high values of x, say $2\frac{1}{2}$ to 3 pounds of combustible per square foot of heating surface, or 100 to 120 pounds per square foot of grate per hour. It should hold, however, for values of x much greater than any plotted by Mr. Christie.

In experiments made by the United States Navy,* the results are closely expressed by the following equations:

$$y = 14.3 - 4.5\sqrt{x} \text{ for water-tube boiler.}$$
$$y = 14.3 - 5\sqrt{x} \text{ for tubular boiler.}$$

I have drawn a curve on each of the Diagrams III., V., and VII., respectively corresponding in character to curves represented by the equation as stated above. The equation of the curve which agrees most closely with the results on Diagram III., AB, for vertical boilers (Fig. 81), is

$$y = 14.3 = 5\sqrt{x'},$$

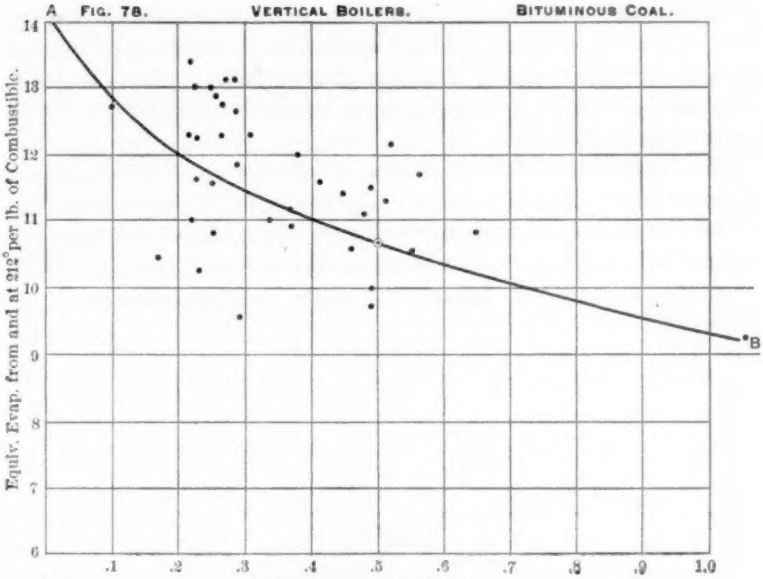
in which x' equals coal per square foot of heating surface per hour; that with the results shown on Diagram V., AB, for horizontal boilers (Fig. 82), anthracite coal, is

$$y = 14.3 - 6.7\sqrt{x}.$$

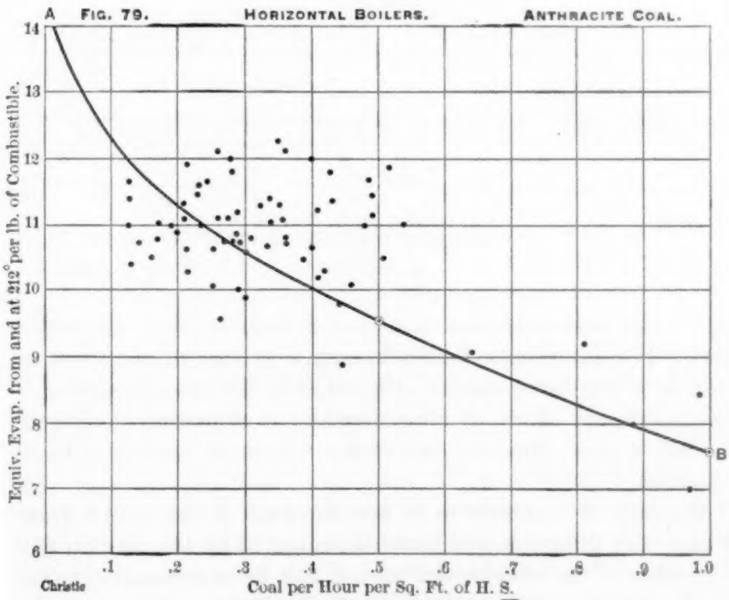
These two curves agree as closely as possible with the widely divergent results plotted, and indicate in both cases a loss of efficiency with anthracite coal which increases with the square root of the amount of coal consumed.

The same curve $y = 14.3 - 6.7\sqrt{x}$ is plotted at AB on Diagram VII. (Fig. 83), for horizontal boilers with bituminous coal, and is seen not to apply, or at least not to agree, with the plotted results. The straight dotted line CD will agree with the plotted

* Referred to in vol. ii., Weisbach's *Mechanics*; *The Steam Engine*, by Bull.



Coal per Hour per Sq. Ft. of H. S.
Equation of Com. $y = 14.3 - 5\sqrt{x}$
FIG. 81.



Coal per Hour per Sq. Ft. of H. S.
Equation of Com. $y = 14.3 - 6 \cdot 7\sqrt{x}$
FIG. 82.

results probably as closely as any line can; the equation of this line is $y = 14.3 - 8.3x'$, and indicates a loss of efficiency increasing directly with increase in the rate of combustion. Such a condition can, of course, only exist even approximately for moderate rates of combustion.

The diagrams all show, however, a decrease in efficiency due to increase of rate of combustion. It should be remarked here that while this condition is in general true, and perhaps always true when the heating surface is equally efficient at all rates of firing,

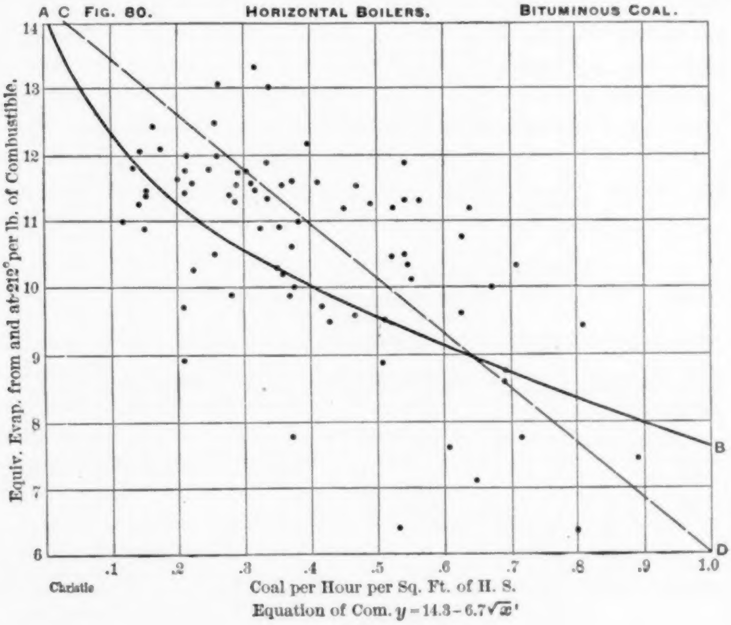


FIG. 83.

it is, on the contrary, often not true, especially with water-tube boilers. For instance, a boiler having a setting of the class as indicated in the above sketch (Fig. 84) will doubtless be found to have a maximum efficiency corresponding to some rate of combustion, and a less efficiency either for a less or greater rate of combustion.

If the rate of combustion is low, the path of the heated gases will take the direction and location indicated by the arrows, and that portion of the boilers at C and F will be comparatively cool and of little service; as the rate of combustion increases, the

hot gases fill the entire space of the boiler more and more nearly, and the highest economy is only reached when the passages AB and ED are well filled with hot gases. I have taken temperatures at different portions of a boiler, and have found that the thermometer readings indicated the existence of conditions as described. This is not said to criticise this form of setting; on the contrary, it is probably as good as any desired, and all settings of water-tube boilers are probably open to the same objection.

I made at one time a series of tests on a water-tube boiler, set in a somewhat similar manner, and in that case found an increase in economy with an increase in the rate of coal consumption,

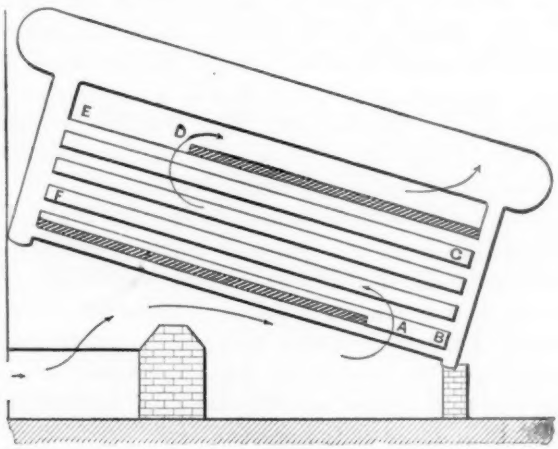


FIG. 84.

from the lowest to the highest limits possible under the existing conditions of draft and grate.

Mr. William Kent.—The high position which the vertical boiler shows in Mr. Christie's paper is due to his including in it some reported results which should not be believed. That is, such a result as 12.47 and 12.85 pounds of water with anthracite coal, and, with bituminous coal, such a figure as 13.40. Striking out these figures, it changes the appearance of the diagram considerably and modifies the conclusion to be drawn from it. The remarkable thing shown about these tests is that with the vertical boilers, with both anthracite and bituminous coal, the highest evaporation recorded, and the lowest, is found at the same rate of combustion of coal per square foot of heating surface. We have

been trying for some time to find what ratio there is between the rate of driving and the economy of the boiler. According to these diagrams there is no relation whatever, because we can get both the highest results and the lowest results in the vertical boilers with the same rate of driving. I am glad to see that Mr. Christie has come to the opinion I expressed last year, and he puts it in almost the same language, namely, that the location in the diagrams of most economical performance seems to him to be within a certain area rather than on a particular line. I expressed that opinion in the discussion of Mr. Hale's paper last year, and went a little further and stated that the breadth of that area is the measure of our ignorance on the subject of boiler economy. The economy of a boiler depends on a greater number of different conditions other than the one condition of rate of evaporation, and starting with that fact as a basis, we should try to find out what conditions, other than the rate of evaporation, influence the economy of a boiler. Of these conditions Mr. Christie's paper gives us no knowledge whatever.

Mr. L. S. Randolph.—There is one suggestion I would like to make. In looking over this paper I think it would be a very valuable improvement if the type of boiler were more definitely indicated, viz., if it is a vertical boiler, a water tube or fire tube, straight tube or "bent tube boiler, with horizontal drums." This was suggested by a fact which Mr. Kent has called attention to, that in these vertical boilers are included some figures which are, to say the least, in doubt at the present time.

*Mr. W. W. Christie.**—We will all, no doubt, profit by the discussion of this paper, and it is gratifying that my assertion of a year ago, that the efficiency of evaporation in a given boiler decreases as the rate of combustion increases, is in the main sustained. As to Mr. Randolph's suggestions, life is too short, and my time too much occupied, to go into the detailed statements noted.

* Author's closure, under the Rules.

DCCLXVI.*

CAST IRON UNDER IMPACT.

BY W. J. KEEP, DETROIT, MICH.
(Member of the Society.)

THE object of the experiments described in this paper was to determine the influence of shock upon cast iron.

They incidentally show the use of mechanical analyses in determining the causes of physical changes which take place in cast iron.

The kind of shock considered is a blow, which shall not produce distortion, delivered on a test bar. Blows were delivered by hammers of various weights, on different parts of test bars, and also by dropping test bars 3 inches and allowing them to strike endwise on an anvil. Test bars were also subjected to shock by tumbling them in a tumbling barrel. The following observations were made :

Striking Test Bars on the Side Decreases their Length.

The decrease is so small that it is difficult to eliminate errors in taking measurements. The greatest care was taken in the Series *a* and *b*, Table I., to avoid error. The average of 19 pairs of bars, Series *a*, shows that 10 blows with a ½-pound hammer on the side of a test bar ½ inch square by 1 foot long shortens it .0001 of an inch. (See also Series *b*.) Ten blows on the side of another single bar made it .0005 shorter. On still another, .00012 shorter. See also Table II., with 50-inch bars.

The measurements of decrease or increase in length were made as follows : All test bars were cast in green sand moulds in which were bedded cast-iron yokes. Between the sides of the test bar and the yoke was one inch of sand. The inner end surfaces of the yokes formed the ends of the mould ; they were parallel, and they slightly chilled the ends of the test bars. The test bar and the yoke were placed upon the follow board in

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

exactly the same position which the pattern and yoke had occupied when the mould was made, and this relative position was at all times maintained. When both test bar and yoke were of the same temperature as the atmosphere, a taper scale graduated to thousandths of an inch was passed between the chilled end of the bar and the face of the end of the yoke, and the reading on the scale recorded. The space just measured was closed by shoving the end of the test bar against the end of the yoke, and the space at the other end was measured. The reading was taken to one quarter thousandths of an inch. The average of the two readings on the scale showed the shrinkage of the bar. After treatment, the distance between the ends of the bar and the yoke was again measured. The difference between this and the original measurement is the gain or loss in length. Gains are + and losses –. The numbers recorded are in most cases averages of the measurements of several bars. The figures, therefore, appear to indicate closer readings than quarter thousandths.

All test bars of Tables I. and III. were 12 inches long and ½ inch square (except Series *l*). Series *a* and 7 are from the same bars, as are *b* and 33. The series 6 to 14 are each made by combining the test bars of five separate tests, of which the measures of length are shown in series *c* to *g*. When the desired number of blows had been delivered, the bars were measured. After a sufficient number of additional blows were given to complete another number, each bar was measured again, and so on.

The bars of Series *h* are the same as in Series 15 to 17. Series *i* and 41 are the same, so are *j* and 42. The strength of bars of Series *k* are not given. The strength of the bars of Series *l* is to be determined. In Series *m* to *r* the bars were measured each time that they were removed from the tumbling barrel. Series *m* and 18 are from the same bars, so are *n* and 19, *o* and 44, *p* and 45, *q* and 46. The bars of Series *r* were not tested for strength. The diagram at the top of Table II. and the description given in the table and text, I think, explain the records. In all cases, in all tables, the record is the change in the total length of the test bar.

Four test bars ½ inch square × 12 inches long, protected by two thicknesses of thin sheet iron from all contact with other castings, were placed in a tumbling barrel and were tumbled for

TABLE I.

DECREASE IN LENGTH FROM BLOWS.

No. Series.	Average No. Bars.	10 Blows on Side at Ends.	1 Blow on Left End.	1 Blow on Right End.	2 Blows on Right and Left End.	1 Blow Each End. 1½-lb. Hammer.	
a......	19	.00010	.00059	.00071	.00077	.00088	
b........	5	.00003	.00020	.00045	....	.00060	After tumbling 3 hours = .00302.

No. Series.	Average No. Bars.	1 Blow on Right End.	1 Blow on Left End.	100 Blows One End.	3,000 Blows One End.	6,000 Blows One End.	9,000 Blows One End.	12,000 Blows One End.	15,000 Blows One End.	18,000 Blows One End.
c.......	3	.00021	.00042	.00054	.00067	.00067				
	4	.00067	.00087	.00100	.00112	.00134	.00153			
	3	.00021	.00037	.00050	.00058	.00066	.00075	.00083		
	3	.00063	.00080	.00109	.00109	.00109	.00126	.00126	.00134	
	3	.00091	.00097	.00116	.00116	.00125	.00129	.00133	.00146	.00175
d.......	5	1 blow was struck on this end.	.00075							
	5		.00070	.00070						
	5		.00048	....	....	.00083				
	5		.00068	....	....	....	....	.00018		
	5		.00080	....	....	....	....	....	....	.00093
e.......	5	.00040	.00055							
	5	.00022	.00072	.00075						
	5	.00038	.00068	....	.00033					
	5	.C0035	.00053	....	....	.00073				
	5	.00030	.00070	....	....	....	.00083			
	5	.00017	.00030	....	....	....	....	.00073		
	5	.00030	.00038	....	....	....	....	....	....	.00053
f.......	4	.00047	.00071							
	3	.00041	.00083	.00141						
	3	.00025	.00062	After tumbling 3 hours was 2.58 longer.						
g	13	.00022	.00050							
h.......	5	.00043	.00075	After 100,000 blows was .00080.						
	5	.00037	.00119	" 250,000 " " .00067 gain in length.						
	5	.00025	.00055	" 500,000 " " .00117 from wear.						
i.......	1	.00062	.00150	After 5,000 blows = .00431 pig-iron No. 1 Silvery De Bar.						
	1	.00025	.00075	" " " = .00418 " " 1 Soft "						
	1	.00100	.00100	" " " = .00325 " " 1 Foundry "						
	1	.00031	.00031	" " " = .00075 " Mottle "						
j.......	1	.00050	.00075	After 5,000 blows = .00088 pig-iron No. 2 Silvery De Bar.						
	1	.00045	.00075	" " " = .00100 " Poor " "						
	1	.00062	.00087	" " " = .00187 " No. 2 F'y Woodward.						
k.........	14	.00070	.00086	After 1 blow on each end .00092 bars 10 years old.						
l.......	4	....	.00050	Test bars 1″ □ × 1′ long.	....	....	.00150			
	4	....	.00044		...	....	....	....	....	.00175
	4	.00094	.00100		After tumbling 3 hours = .00132					
	2	.00031	.00031		" " 6 " = +.00037 (longer).					

three hours. The average shortening was .00065 inch. In this case there could have been no wear on the ends. One test bar from each of various brands of pig-iron was protected by one

thickness of sheet iron, and was tumbled three hours. The amount of shortening is given in Table X., Series 39 and 40.

Of 11 test bars, Series *m*, Table III., tumbled in contact with other castings for half an hour, 6 bars had become shorter, 4 measured the same as when put in, and 1 had grown longer.

Blows on the End of a Test Bar Shorten it.

Series *a*, Table I., is most free from error. A blow was first delivered on one end. The test bar was held in a vertical position, its lower end resting on a pine board two inches thick. Half of a broken test bar was held on the end, slanted slightly from vertical, to allow one edge of the lower end to rest across the centre of the chilled end of the test bar. One blow was struck on the upper end of the half bar and was transferred to the upper end of the test bar. There was thus little danger of upsetting the end of the test bar. The shortening was five times as great as with ten blows delivered on the side of the same bar with the same hammer. A blow delivered in the same way on the other end showed a shortening only one-fifth of that due to the first end blow. A piece of lead was then placed on the end of the test bar, and two blows with the $\frac{1}{2}$-pound hammer were struck on each end, and the effect was less than the second single end blow. On the same lead, one blow was struck on each end by a $1\frac{1}{4}$-pound hammer, with an effect about equal to either of the single end blows. The other series in Table I. may not have been quite as free from error, though at the time of making the experiment it was supposed that every precaution was taken to avoid error.

A blow seems to exert the greatest influence in the direction in which it is delivered. It is difficult to determine whether the shortening which follows an end blow is caused by a general rearrangement of crystals, or by an upsetting of some portion of the bar. If the latter, cast iron is upset by a very slight blow.

In Table II. the lower end of the 50-inch bars rested on the wooden floor and the upper end was steadied by the hand. I endeavored to measure the change in the length of the bar when the gates were broken off, but there were so many chances that the bar lay in a slightly different position when measured that the records are not given. If further experiment should show that the casting becomes shorter when struck with a ham-

mer, it will in part explain the frequent cracking of a casting by rapping off the gates, as in the case of a pulley with light arms. If a blow exerts this influence, we can understand the frequent change in shape of many castings. I have a planing machine made to dress pine lumber to $\frac{1}{32}$ of an inch thick, and it is very difficult to keep the upper surface of the bed true.

To ascertain if shipping castings by railroad would affect them, I packed 7 test bars in excelsior, wedged 6 bars tight in a box, and packed 6 test bars loosely in another box, so that they would always lie two deep. I sent them on the floor of a box car over the railroad between Detroit and Chicago four times. The first two sets showed no change. If the measurements were correct, the bars packed loose were a trifle shorter (.00006), but there might have been an error, as the first and last measurements were taken twenty days apart.

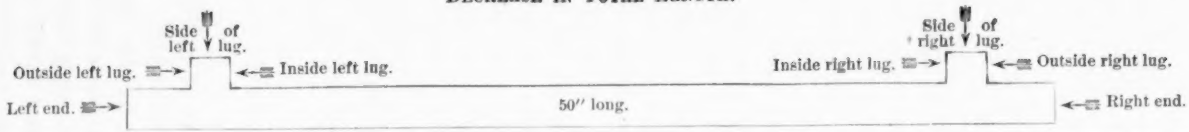
In Table I. each of the series shows the influence of a small number of blows on the end of a test bar, and Series *c* to *j* show the amount that a larger number of blows shorten test bars. In Series *c* it is possible that the end of the test bar was worn slightly. Series 1 is of test bars $\frac{1}{2}$ inch square × 12 inches long. The shortening influence of blows is as apparent as in the small bars. Some of the shortening of bars which received a large number of blows may be due to wear. Tumbling three hours may have shortened the bar even more than 18,000 blows, and the bar at the same time may have been stretched by the pounding action of the other castings, and thus make the record smaller. Tumbling six hours has entirely overcome the shortening, and the test bar is longer than when placed in the tumbler. The bars of Series *h* showed wear plainly on the end of the bars.

Test Bars Tumbled in Contact with Other Castings in a Tumbling Barrel Increase in Length.

This is in proportion to the malleability of the iron, and is caused by the peening action of the other castings. A test bar $\frac{1}{2}$ inch square × 12 inches long was held in the hand by one end, and 500 blows were delivered with a $\frac{1}{2}$-pound hammer on the four sides of one end, the blows not reaching more than one inch from the end. The bar was lengthened .00025 inch. Five hundred blows one inch from the other end lengthened the bar as much more, making it .0005 inch longer. This shows that

TABLE II.

Decrease in Total Length.



		Test Bars 1″ □ × 50 Inches Long.							Bars ½″ × 50″ Long.			
		1	2	3	4	5	6	7	8	9	10	11
		Blows struck on lead with a ½-pound hammer.										
1	Blow on side of right lug	On 2 other bars with a 1½-lb. hammer: 1 bl. ins. rt. lg. = .00087; 1 " " " " = .00112; 50 " " " " = .00162	The other bar: 1 blow on inside right lug = .00200. 100 blows on inside right lug = .00225.	......	.00062	0–	.00050	.00025	.00038	.00200	.00038	.00038
1	" " " " " "			......	.00075	.00044	.00050	.00050	.00075	.00212	.00038	.00044
2	" " " " left "			......	.00075	.00056	.00050	.00050	.00112	.00212	.00050	.00044
50	" " " " right and left lug			......	......	......	.00075	.00062	......	......	.00050	.00062
1	" " inside right lug			......	.00100	.00056	.00081	.00125	.00112	.00237	.00062	.00062
1	" " " " "			......	.00100	.00069	......	......	.00112	.00237	......	......
50	" " " " "			......	.00112	.00069	......	......	.00112	.00250	......	......
100	" " " " "			......	.00137	.00069	......	......	......	......	......	......
1	" " " left "			......	......	......	.00081	.00125	......	......	.00062	.00062
50	" " " " "			......	......	......	.00081	......	......	......	.00062	.00100
50	" " " " "			......	......	......	.00087	......	......	......	.00075	.00100
50	" " " " "			......	......	......	.00112	......	......	......	.00075	.00125
	After cooling ½ hour		......	......	......	......	.00162	......	......	......	.00175	.00225
1	Blow on right end	.00175	......	......	......	......	.00187	......	......	......	.00200	.00250
50	" " " "	......	......	......	......	......	.00187	......	......	......	.00262	.00250
1	" " left "	.00200	......	......	.00137	.00069	......	......	......	.00250	......	......
50	" " " "	......	......	......	.00162	.00094	.00206	......	.00200	.00312	.00275	.00275
50	" " " "	......	......	......	.00175	.00094	.00237	......	.00237	.00312	.00275	.00300
50	" " " "	......	......	......	.00175	.00106	......	......	.00244	.00312	......	......
	After cooling ½ hour	......	......	......	......	......	.00300	......	......	......	.00312	.00375

		Blows struck on lead with a 1½-pound hammer.										
1	Blow on side of right lug	On another bar: 50 blows on one lug = .00050. 350 blows on both lugs = .00075.	......	.00050								
1	" " " " " "		......	.00050								
2	" " " " " "		......	.00062								
2	" " " " " "		......	.00062								
50	" " " " " "		......	.00062								
50	" " " " " "		......	.00075								
50	" " " " " "		......	.00075								
50	" " " " " "		......	.00075								
50	" " " " left "		......	.00087								
50	" " " " " "		......	.00087								
50	" " " " " "		......	.00087								
50	" " " " " "		......	.00087								
1	" " right end	.00250	.00250	.00137	......	......	.00300					
1	" " " "	......	.00287	.00200	......	......	......					
1	" " " "	.00250	.00287	.00200	......	......	.00325	......	......	......	.00350	.00400
50	" " " "	.00325	......	......	......	......	......	......	......	......	......	......
1	" " left "	.00325	.00358	.00212	......	......	......	......	......	......	......	......
1	" " " "	......	.00400	.00262	......	......	......	......	......	......	......	......
50	" " " "	.00325	.00400	.00300	......	......	.00350	......	......	......	.00362	.00412
50	" " " "	.00325	.00475	.00387	......	......	.00375	......	......	......	.00362	.00412
50	" " " "	.00325	.00475	.00487	......	......	.00375	......	......	......	.00362	.00412
50	" " " "	.00337	.00475	.00487	......	......	.00375	......	......	......	.00362	.00412
50	" " " "	.00337	.00475	......	......	......	.00375	......	......	......	.00362	.00412
100	" " right "	.00337	.00500	......	......	......	......	......	......	......	......	......
50	" " " "	.00350	.00512	......	......	......	......	......	......	......	......	......
50	" " " "	.00350	.00512	......	......	......	......	......	......	......	......	......
600	" outside right end	......	......	.00487	......	......	......	......	......	......	......	......
	After cooling ½ hour	......	......	......	......	......	.00412	......	......	......	.00400	.00450

the peening action of such light blows delivered on the loose end of a test bar for only two inches of its whole length increases its length.

One bar was struck 1,000 blows with a ½-pound hammer, on only one side, for four inches in length at the centre, until the surface was smooth, the other side resting on an anvil. The bar was .00325 inch longer.

The test bars which received a quarter and a half million blows (Series *h*, Table I.) were placed, four in each compartment, of a specially prepared striking machine, and they bumped against each other and against the wooden sides of the compartments which held them, until their sides were worn smooth. Perhaps this action peened the sides and caused the bars to become slightly longer. As the ends of all bars treated in this way were chilled, the wear would be very slight, and on bars receiving less than 18,000 blows, probably not enough to be measured. Other test bars receiving 1,000 blows from a ½-pound hammer, on one side, leaving 1½ inches at centre untouched, lengthened the bar .00225 inch. Test bars in a tumbling barrel are more like bars held in the hand and struck with a very light hammer, though they receive some blows while they rest on the side of the barrel.

All tumbled bars reported in this paper were measured, and gained in length. The gain of a number of bars is given in Table III., Series *m* showing the gain at the end of each half hour. Series *n* shows the gain in length when tumbled ten hours. That the gain in length is not due to any change in arrangement of crystals is shown by the record of test bars of steel and wrought iron (Series *r*). A tempered steel bar changed very little. The same tool steel not tempered was slightly longer. A bar of Bessemer steel lengthened as much as the cast-iron bars. The wrought-iron bar was so soft that at the end of one hour the ends were worn round, and the bar was .0012 inch shorter from wear than when put in. At the end of two hours the ends continued to wear rapidly, but the peening of the sides lengthened the bar .00087 inch, and at the end of three hours .00187 inch. It was the action of tumbling on this non-crystalline bar that suggested the same cause for the lengthening action on cast iron.

TABLE III

NUMBER OF HOURS TUMBLED AND INCREASE IN LENGTH.

No. Series.	Av. No. of Bars.	¼ Hour.	1 Hour.	1½ Hours.	2 Hours.	2½ Hours.	3 Hours.	3½ Hours.	4 Hours.	4½ Hours.	5 Hours.	6 Hours.
	2	.00012										
	2	.00010	.00100									
	2	.0	.00050	.00138								
	2	.00019	.00012	.00106	.00206							
	2	.0	.00025	.00081	.00150	.00169						
m........	2	.0	.00025	.00087	.00125	.00162	.00162					
	2	.0	.00019	.00056	.00175	.00182	.00225	.00250				
	2	.00013	.00100	.00100	.00100	.00119	.00135	.00135	.00194			
	2	.00006	.00044	.00082	.00132	.00150	.00163	.00163	.00163	.00163		
	2	.00040	.00038	.00125	.00144	.00144	.00157	.00157	.00157	.00200	.00231	
	1	.00075	.00075	.00025	.00150	.00175	.00175	.0175	.00175	.00175	.0175	.00175

No. Series.	No. Bars.	1 Hour.	2 Hours.	3 Hours.	4 Hours.	Increase in Length.	No. Hours.
	1	.00250					
	1	....	.00000				
	1	....	.00450	.00450			
	1	....	.00400	.00400	.00400		
	1	....	.00350	.00400	.00350	−.00250	5 Hours.
n..........	1	....	.00300	.00400	.00350	.00250	6 "
	1	....	.00400	.00400	.00400	.00450	7 "
	1	....	.00350	.00350	.00325	.00250	8 "
	1	....	.00400	.00450	.00500	.00400	9 "
	1	....	.00200	.00200	.00200	.00100	10 "

No. Series.	No Bars.	Name of Pig-Iron.	1 Hour.	2 Hours.	3 Hours.
	2	1 Silvery De Bar....	.00058	.00150	.00212
	2	1 Soft "	.00212	.00200	.00200
o..........	2	1 Foundry "	.00100	.00156	.00200
	2	Mottle "	.00076	.00076	.00094
	2	White "	.0	.0	.0
	2	2 Silvery De Bar.....................	.00156	.00325	.00375
	2	3 " "	.00100	.00212	.00219
p..........	2	2 Soft Rockland.....................	.00100	.00125	.00156
	2	Poor "	.00069	.00133	.00133
	2	2 Foundry Woodward.....................	.00112	.00256	.00287

q........... 3 bars each of Dayton pig iron tumbled 2 hours = Close Silvery .00125, Open Silvery .00250, 2 Foundry .00100, 1 Mill .00150, Open Bright .0, Open Bright .00075, 2¼ Foundry .00025, Mottle .00100, 2 Mill .00150.

r........... A tempered tool-steel test bar tumbled 1 hour .00019, 2 hours −.00013, 3 hours −.00006. Same steel untempered 1 hour .00087, 2 hours .00012, 3 hours .00050. Bessemer bar 1 hour .00150, 2 hours .00200, 3 hours .00300. Wrought-iron bar 1 hour −.0012, 2 hours .00087, 3 hours .00187.

STRENGTH AND IMPACT.

Are Test Bars Strengthened by Impact?

It is a difficult thing to impart shock to a test bar without changing in some way the character of its surface. In every case the experiments described in this paper were made with pairs of test bars cast from one gate, and marked 1 and 2. No. 1 bar was tested in its original condition as it came from the

sand. No. 2 was treated by impact. The two bars are then tested transversely on an autographic machine, and the variation of the record of No. 2 from that of No. 1 is considered the result of impact. Unless otherwise stated, the test bars are ½ inch square by 12 inches long. It is necessary to call attention to the following facts regarding cast iron:

It is not an alloy, but a mixture of iron with from 5 to 10 per cent. of metalloids. This mixture is partly chemical and partly mechanical, and is not uniform.

The strength of a casting is dependent upon the character of its crystals or grains. Large grain, or grains loosely interlocked, invariably produces weakness.

The character of grain depends upon the size of the casting, upon the various local conditions attending melting and the entrance of the iron to the mould, and upon the chemical composition of the metal.

The lack of homogeneity is such that it is a rare thing for even the two test bars which are cast together to have the same strength.

Taking all of these things into account, we must not attach importance to the variation of the bars of any single pair, but must consider averages; or it is better to consider tendencies. If the general tendency of the records of a series of tests is in any direction, it should receive consideration. If there are as many pairs of bars which show an opposite tendency, the fact of the tendency in one direction being greater does not necessarily show that the greater variation is caused by the treatment. One large variation on one side and several small variations on the other may show an average on the side of the large variation, while such large variation may have been caused by some condition which cannot be located, and yet which is not caused by the treatment. Both tendencies and averages should be considered. If enough tests could be compared, tendencies and averages would agree. When the tendency is all in one direction, without exception, there can be little doubt of its reliability. The first method of imparting impact was:

Shipping Test Bars by Railroad, in an ordinary box car, more than 1,000 miles, between Detroit and Chicago. Seven test bars were packed in excelsior so that they did not touch each other or the sides of the box; six bars were packed in contact with each other and were wedged so that they could not move.

Six bars were placed in a box so that they would always lie two deep and could move when a jolt occurred. Seven bars were placed in a tumbling barrel and tumbled two hours. The difference in strength between No. 1 bars, which were in the condition in which they left the mould, and the No. 2 bars, which received the treatment, is shown in Table IV., Series 1 to 4. We know that the bars packed in excelsior would receive the least shock, those wedged tight a trifle more, and those packed loose must have jolted more or less. The results, therefore, indicate that the bars were not strengthened by impact.

TABLE IV.

SHIPPED BY RAIL.

Series 1. Excelsior.			Series 2. Wedged Tight.			Series 3. Packed Loose.			Series 4. Tumbled 2 Hours.		
Orig'l.	R.R.	Diff.	Orig'l.	R.R.	Diff.	Orig'l.	R.R.	Diff.	Orig'l.	Tumb'd.	Diff.
360	368	8	348	388	40	352	340	−12	365	420	65
362	368	6	370	378	8	360	385	25	377	400	23
365	350	−15	380	380	0	375	380	5	378	400	22
365	380	15	380	380	0	378	363	−15	385	416	31
378	370	− 8	380	400	20	382	345	−37	388	397	9
382	365	−17	399	388	−11	395	350	−45	390	421	31
385	385	0	...	...	....	...	...	....	398	415	17
371	369	− 2	376	386	10	374	360	−14	383	410	27

It would not be safe to conclude that these bars were weakened, because there are too many variations of the opposite kind, and because all variations are within the amount of variation of pairs of bars not treated at all. (See Tables V. and VII., Series 5 and 28.) The tumbled bars, without exception, show large increase of strength.

Blows Delivered on the Side of a Test Bar with a Hammer.

A thousand blows were given with a ½-pound hammer to the side of a test bar, within one inch of each end, the bar being held in the hand by the other end. As the No. 1 bar broke at 385 and No. 2 at 375, No. 2 was not strengthened by the blows. A test bar receiving 10 blows like the above broke No. 1 at 355 and No. 2 at 360. In another case the average difference of four pairs of bars, of which No. 2 received the same 10 blows, was .57 of a pound less for No. 2. In Series 7, Table V., with nine-

TABLE V.

Blows.

Series 5.

Original.	Original.	Difference.
360	360	0
360	375	15
370	380	10
370	394	24
375	370	− 5
375	375	0
380	360	−20
385	385	0
390	388	− 2
392	397	5
395	360	−35
400	432	32
402	406	4
*424	475	51
426	418	− 8
427	400	−27
430	400	−30
440	400	−40
440	438	− 2
445	440	− 5
463	430	−33
402	399	− 3

Series 6.

Original.	2 Blows.	Difference.
360	375	15
360	395	35
362	358	− 4
362	370	8
370	395	25
376	372	− 4
378	387	9
385	380	− 5
388	345	−43
390	390	0
398	343	−55
399	400	1
400	390	−10
400	390	−10
405	380	−25
408	433	25
410	426	16
427	370	−57
430	430	0
435	472	37
440	445	5
394	393	− 1

Series 7.

Original.	8 Blows.	Difference.
340	363	23
350	350	0
350	365	15
353	364	11
358	355	− 3
362	385	23
364	372	8
368	348	−20
368	370	2
368	378	10
370	362	− 8
370	368	− 2
370	380	10
374	393	19
377	370	− 7
379	357	−22
395	372	−23
396	370	−26
398	370	−28
369	368	− 1

Series 8.

Original.	100 Blows.	Difference.
375	384	9
380	385	5
380	387	7
383	381	− 2
383	383	0
400	400	0
408	400	− 8
415	413	− 2
442	440	− 2
445	405	−40
445	410	−35
405	399	− 6

Series 9.

Original.	3,000 Blows.	Difference.
335	342	7
345	360	15
360	377	17
395	420	25
400	398	− 2
422	401	−21
435	400	−35
385	385	0

Series 10.

Original.	6,000 Blows.	Difference.
359	350	− 9
365	365	0
370	412	42
375	338	−37
375	352	−23
382	415	33
390	390	0
390	435	45
400	400	0
400	437	37
425	426	1
429	412	−17
440	445	5
478	470	− 8
398	403	5

Series 11.

Original.	9,000 Blows.	Difference.
335	345	10
338	363	25
347	363	16
375	393	18
382	393	11
390	385	− 5
390	396	6
426	433	7
373	384	11

Series 12.

Original.	12,000 Blows.	Difference.
340	345	5
375	388	13
376	384	8
380	380	0
388	402	14
395	394	− 1
396	418	22
398	380	−18
402	378	−24
406	440	34
430	430	0
439	446	7
394	399	5

Series 13.

Original.	15,000 Blows.	Difference.
390	393	3
400	420	20
395	406	11

Series 14.

Original.	18,000 Blows.	Difference.
360	375	15
370	396	26
375	385	10
380	416	36
385	380	− 5
398	382	−16
400	390	−10
400	412	12
402	396	− 6
404	391	−13
420	380	−40
420	400	−20
428	419	− 9
396	394	− 2

Series 15.

Original.	100,000 Blows.	Difference.
400	430	30
428	430	2
450	478	28
452	463	11
433	450	17

Series 16.

Original.	250,000 Blows.	Difference.
400	400	0
400	406	6
440	435	− 5
495	490	− 5
495	500	5
518	540	22
458	462	4

Series 17.

Original.	500,000 Blows.	Difference.
400	390	−10
455	456	1
475	500	25
493	480	−13
500	525	25
500	525	25
471	480	9

teen pairs of bars, No. 2 bars received 10 blows with a ½-pound hammer on the sides near the ends; then they received 6 blows (3 on each end) with the same hammer; then 1 blow on each end with a 1¼-pound hammer, 8 in all. In each case the bar rested on an anvil for side blows and on a wooden bench for the end blows. There was no gain in strength.

Blows Delivered on the End of a Test Bar.

A series of 16 vertical compartments 1⅛ inches square and 12 inches deep, with pine partitions 1 inch thick, and a cast-iron bottom 10 inches square and 1 inch thick, were arranged to be lifted suddenly 3 inches by a cam and allowed to fall on a solid foundation. Springs caused the compartments to fall faster than by gravity, leaving the bars to fall of their own weight on the iron bottom. Whether the bars in the compartments fell of their own weight or descended with the compartments, when the iron bottom stopped the bars would receive shock. They rebounded about 3 inches and fell on the iron bottom a second time, and did this several times, each fall being from a less height. The number recorded in the table is the number of times the compartments were raised, and the bars received at least twice that number of blows. One hundred initial shocks were given per minute. The records marked "Original" for both bars are of pairs where both Nos. 1 and 2 are tested as they came from the mould, and show the variation to be expected in untreated bars.

We must not ascribe any difference in strength to treatment, unless the difference always varies the same way, and is large enough to be more than the variation between the No. 1 and 2 bars of original pairs, as Series 5.

In the next record (Series 6, Table V.), the No. 2 bar received a sharp blow from a ¾-pound hammer on each end. No. 2 bars of Series 8 to 17 received blows in the apparatus described. In explanation of the greater strength of both No. 1 and 2 bars of Series 15, 16, and 17, these bars were cast from a stronger iron mixture. (Also see remarks regarding smooth surfaces of test bars.)

There are in these series, taken as a whole, about as many variations showing decrease as increase of strength, while the averages show a slight increase of strength. The increase does not seem to bear any relation to the number of blows received,

and is not sufficiently great or uniform to be of any use as a strengthening agent. There is no indication that the number of shocks imparted have weakened the test bars. It is almost safe to conclude that this amount of shock has not influenced the ability of the test bars to resist a dead load. The third method of imparting shock was—

Tumbling Test Bars in a Tumbling Barrel, along with other castings and with a large quantity of small hard stars. The records of a number of series of tumbled bars are given in Table VI.

TABLE VI.

TUMBLED.

SERIES 18.

No. Hrs.	Original.	Tumbled.	Difference.
1	373	385	12
1½	364	392	28
2	373	390	17
2½	390	408	18
3	380	400	20
3½	347	400	53
4	365	398	33
4½	390	412	22
5	373	395	22

SERIES 19.

No. Hrs.	Av. Orig.	Tumbled.	Difference.
1	373	385	12
2	373	430	57
3	373	430	57
4	373	400	27

The 5th, 6th, 7th, and 10th were 400, the 9th 415.

SERIES 20.

Original.	1 Hour Tumb'd.	Difference.
309	345	36
345	438	83
350	445	95
375	400	25
378	415	37
385	430	45
395	419	24
400	460	60
408	372	−36
410	471	61
433	475	42
435	450	15
448	475	27
450	450	0
455	447	− 8
—	—	—
398	433	35

SERIES 21.

Original.	2 Hours Tumb'd.	Difference.
285	372	87
285	400	115
290	390	100
295	398	103
300	365	65
300	440	140
325	330	5
330	374	44
345	428	83
348	382	34
365	400	35
—	—	—
315	389	74

DUNN SERIES 22.

Original.	2 Hours Tumb'd.	Difference.
400	500	100
448	570	122
455	540	85
460	500	40
490	550	60
502	520	18
512	525	13
520	528	8
—	—	—
473	529	56

SERIES 23.

Record Franklin Institute Committee.

No. Bars.	Original.	Tumbled.	Difference.	Per Cent. Gain.
16	1882.25	2328.50	446.25	23.77
16	1991.50	2397.19	405.69	20.37
16	2127.06	2456.56	329.50	15.49
15	2269.73	2566.00	296.27	13.05

The difference between these series and those which received simple blows is that—

*Tumbled Test Bars are always Stronger than Companion Bars not Tumbled.**

* See records of bars 1 inch square on page 378.

So far as I am aware, this fact was first discovered by Mr. A. E. Outerbridge, of Philadelphia, Pa. He described this in a letter to me in the last part of 1894, and he published a description in *Transactions* of the American Institute of Mining Engineers, vol. xxvi., 1896, page 176. He explains the gain in strength by the "mobility of molecules."

Test bars made on various days in our foundry during the last year were tumbled two hours, and the averages are given in Series 43 of Table X. Out of 87 of these bars, all except 9 increased in strength. These bars may have become wedged so as not to have received any tumbling action.

Test Bars ½ Inch Square Increase in Strength until they have been Tumbled Two or Three Hours, but not Materially by Longer Tumbling.

(Series 18 to 21, Table VI., and Series 33, Table VII.)

I have arranged most of the series so that the weakest No. 1 bar comes first.

I have just received a series of records of original and tumbled bars made by the Committee of Science and Arts of the Franklin Institute. The test bars were 2 inches by 1 inch by 24 inches, tested flat. I discarded the records of defective bars and arranged the records of perfect bars in the order of strength of the original bars, and then divided the list into four equal parts and took the average of each set. The averages are shown in Series 23 of Table VI. The records of the individual test bars of Series 23 will be published in a report by the Committee of Franklin Institute. After arranging the first column of each series with the weakest bars first and the strongest bars last, I thought that the differences between the No. 1, or original, and No. 2, or tumbled, bars showed that tumbling strengthened the weakest bars more than it did the strongest bars; but when I plotted the differences of each series, I found that the same tendency was apparent in the untumbled bars. The reason for this seems to be that the difference in strength between a No. 1 and a No. 2 bar cast together is due to a difference of grain (see Series 24) caused by some local condition, and therefore the weakest No. 1 bar did not necessarily have as weak a No. 2 bar, or the strongest No. 1 bar the strongest No. 2 bar. My first impression led me to think that tumbling removed the cause of weakness. The difference between tumbled and untumbled bars which is most apparent is that the surfaces of the former have been rubbed smooth and have been peened by the blows received from other castings. It appeared that—

The Strength Gained by Tumbling is Due to Making the Surface of the Test Bar Smooth and to Condensing the Surface by Peening.

This was proved by the following experiments.

TABLE VII.

SMOOTHED AND POUNDED.

SERIES 24.

Both	Polished.	Difference.
296	353	57
300	328	28
300	350	50
310	317	7
334	328	− 6
348	370	22
364	285	−79
369	315	−54
370	367	− 3
398	300	−98
339	331	− 8

SERIES 25.

Original.	Polished.	Difference.
356	345	−11
363	400	37
392	390	− 2
393	375	−18
395	338	−57
398	378	−20
398	390	− 8
400	385	−15
405	400	− 5
421	395	−26
392	380	−12

SERIES 26.

Original.	Filed.	Difference.
348	385	37
360	370	10
362	391	29
367	370	3
375	370	− 5
375	392	17
375	397	22
380	345	−35
387	382	− 5
391	390	− 1
372	379	7

SERIES 27.

Original.	Centre Pounded.	Difference.
300	380	80
358	378	20
360	398	38
365	380	15
367	342	−25
372	396	24
354	379	25

SERIES 28.

Original.	Original.	Difference.
363	384	21
365	378	13
365	382	17
380	380	0
383	370	−13
371	379	8

SERIES 29.

Original.	One Spot Pounded.	Difference.
350	367	17
353	370	17
358	363	5
375	365	−10
359	366	7

SERIES 30.

Original.	All except Centre Pounded.	Difference.
355	392	37
358	380	22
374	381	7
375	380	5
375	385	10
367	384	17

SERIES 31.

Original.	Centre Pounded.	Difference.
338	400	62
340	405	65
367	390	23
377	398	21
378	402	24
360	399	39

SERIES 32.
Tumbled 3 Hours.

Original.	Protected.	Difference.
345	349	4
345	382	37
347	340	− 7
348	360	12
360	380	20
349	362	13

SERIES 33.
Tumbled 3 Hours.

Original.	Tumbled.	Difference.
357	391	34
369	390	21
369	405	36
370	400	30
370	402	32
367	398	31

The Removal of the Surface Weakens a Test Bar.

The surface of both No. 1 and 2 bars in Series 24, Table VII., was removed by polishing to make the surfaces and corners perfectly true. The object was to see if the variation in strength between No. 1 and 2 bars in any pair depended upon irregularity in the surface or in the crystals near the surface, and if by removing them the bars would show less variation. The result shows that the variation in Series 5, Table V., was due to variations in the interior structure of the bars as well as to the character of the surface; and by comparing with No. 1

bars of Series 25, which was made at the same time, it is seen that the removal of the surface has materially weakened all of the bars. To collect further proof of this, the No. 1 bars of Series 25 were tested as they came from the sand, and the No. 2 bars were polished simply enough to give a true surface. No. 2 bars are so much weaker than No. 1 that much of the surface must have been removed in the effort to obtain a true surface.

Smoothing the Surface of a Test Bar without Removing the Surface Strengthens it.

In Series 26 the surfaces of the under side of the No. 2 test bars were smoothed with an old file simply to remove the projecting points, the surface being cut as little as possible. The result is a decided gain in strength.

TABLE VIII.

DIFFERENT GRADES OF SAND.

Series 35. Fine Brass Sand.			Series 36. Stove Plate Sand.			Series 37. Machinery Sand.		
Original.	Filed.	Difference.	Original.	Filed.	Difference.	Original.	Filed.	Difference.
362	378	16	367	355	– 12	332	380	48
355	378	23	375	385	10	390	425	35
373	360	– 13	377	396	19	360	385	25
375	378	3	395	396	1	379	440	61
398	400	2	400	418	18	362	385	23
420	430	10	443	451	8	400	450	50
380	387	7	393	400	7	370	411	41

Series 35, 36, and 37 are made with different grades of moulding sand, fresh sand with no facing or sea coal being used. There was no difference discernible between the surface of the bars of Series 35 and 36, but the bars made in the machinery sand, Series 37, were very rough. I have proved before that iron last poured from a ladle will make stronger test bars than the iron which is poured first. (See Table IX.) To prevent this fact having any influence on these series, the flasks were located so that the flask containing the first pair of bars of each series was poured first in the order 35, 36, and 37; then the three flasks containing the second pair, and so on. The sixth pair of Series 37, being poured the last, should have been the strongest if there had been no local influence to prevent it. The under

surface of the No. 2 bars of each series was filed smooth with an old file. There was a decided gain in the strength in the No. 2 bars of each series. The surface of the bars made in machinery sand was very rough, and the gain from smoothing was therefore much greater. A close inspection of these records will be of great interest. The average of the No. 2 bars shows a gain in strength of about 11 pounds in each series due to the later pouring. No. 1 bars of the stove plate series are 13 pounds stronger than those made in brass sand, and no doubt the weakness of No. 1 bars in the machinery series is due to the projecting irregularities of surface caused by coarse sand, because a removal of these rough projections restores the strength in No. 2 bars. This weakness of the No. 1 bars of the machinery series and the increase in strength in nearly all cases of the No. 2 bars of all three series proves that a smooth surface makes a stronger test bar, provided the surface is not removed. By filing, some of the surface is necessarily removed, while by the pounding in a tumbler none of the surface is removed. Sea coal in machinery sand prevents the iron penetrating the recesses between the coarse grains and makes a smoother casting, and perhaps the last iron from the ladle, being colder and less fluid, will not take a sharp impression of the mould, and thus it may have a more even surface.

Smoothing the Surface of a Test Bar by Pounding with a Hammer Increases its Strength.

In this case, Series 27, Table VII., nothing is removed, and the projecting roughness is driven into the surface. The under surface, for 4 inches at the centre, received 1,000 light blows from a ½-pound hammer. The rest of the surface was not touched. The gain is equal to that by tumbling.

Pounding the Surface of a Test Bar Strengthens it by Condensing the Grain.

A new pattern was used for the series of tests 28 to 33, and for those made afterwards. To insure the utmost accuracy the greatest care was taken to have all corners right angles, both dimensions .500 inch, and all surfaces true. It happened that with Series 28, in which both Nos. 1 and 2 bars were tested just as they came from the sand, the amount of variation in strength was no less than before. In Series 28 the average strength of

the No. 2 bars was 7 pounds stronger than the average of No. 1. As each series from 28 to 33 were poured from the same ladle, it may be taken that all No. 2 bars were 7 pounds stronger than No. 1 before treatment; that is, 7 pounds should be subtracted from each before comparison. Or, if thought best, the variation in Series 28 may be considered an exception, for in other series made afterwards the bars were nearly alike. This is another example of the danger of noting individual or small variations. In Series 29 each of the No. 2 bars received 1,000 blows in one spot near the ends from a ½-pound hammer to ascertain the influence of simple impact. Compared with Series 28 there is no gain. The No. 2 bars of Series 30 received 1,000 blows from the same hammer, distributed over the whole surface except for 1½ inches at the centre, which was left untouched. At the point of fracture, therefore, the surface of No. 2 was the same as that of No. 1. The No. 2 bars were stronger than No. 1, indicating that some of the gain in tumbling may be due to peening the surface of the bar. Another bar, treated in exactly the same way, stretched two and one-quarter thousandths of an inch by the blows, but No. 1 broke at 390, and No. 2 at 395. The bars of Series 31 received 1,000 blows from the same ½-pound hammer on the under side for four inches at the centre, so that the surface at the point of fracture was both smooth and peened. The gain in strength, like that of Series 27 and 31, was equal to the gain by tumbling (Series 33).

To avoid the possibility of a mistake, I adopted another method of separating the influence of blows on the surface and smoothing the surface. Each of the No. 2 bars of Series 32 was covered by two thicknesses of ductile sheet iron, so that no direct blows could reach the surface of the bar, and the surface could not be rubbed. These protected bars were tumbled three hours along with the No. 2 unprotected bars of Series 33, and with other castings. The No. 2 bars of Series 32 and 33 must have received the same treatment. The sand on the under surface of the No. 2 bars of Series 32 was apparently undisturbed, as in the No. 1 bars. If there was a gain in strength, it was probably due to the blows on the surface acting through the sheet-iron covering.

In Table X., Series 39 and 40, several test bars from pig-irons were tumbled three hours while protected by one thickness of sheet iron. The surfaces were pounded quite smooth and all

sand was worn off, and the influence is less than the same iron tumbled without cover. The regularly tumbled bars of Series 33 show the same decided gain in strength as in all cases of milling. The bars which received from 0 to 100,000 blows, Series 5 to 17, Table V., were tested before it had occurred to me that the smoothness of the surface had anything to do with strength. The bars receiving 100,000 blows were worn quite smooth. Not expecting anything of this kind, I had placed four in a compartment of the apparatus for imparting blows, and they rubbed against each other, and when taken out had perfectly smooth and bright surfaces, which were no doubt peened more or less. Noticing this, in bars receiving a greater number of blows I rubbed the surfaces of No. 1 bars near the centre quite smooth with an old file, and may have injured the surface somewhat. It was this experience which suggested that smoothness might influence strength of castings. It was after this that the experiments with polished, smoothed, and pounded surfaces were made. If I had not noticed the smoothness of these No. 2 bars and had tested the No. 1 bars without smoothing the surface, the No. 2 bars might have shown a greater gain in strength, with resulting conclusions very different from those finally arrived at.

ARE TUMBLED CASTINGS ANNEALED?

In 1894 I published the following record, Series 38, Table IX. (*Transactions* A. S. M. E., vol. xvi., p. 568). This record shows that annealing by heat causes a test bar to become longer. If the test bar before annealing is weak on account of brittleness, it grows stronger; but if, as in this case, it was not brittle, annealing weakens it. Deflection is increased 35 per cent.

Total carbon remains the same; most of the combined carbon is changed into graphite. All other elements remain substantially unchanged. In annealing by heat the test bar is heated nearly to fusion, and is thereby lengthened to the utmost extent and held there long enough for the carbon to change to graphite and for the crystals to rearrange themselves. When the casting cools, it does not regain its former length, but is longer than before annealing.

Tumbling reverses this process, and, by pounding, stretches the sides and presses apart the crystals of the inner portion of the test bar, and increases its total length. It has just been

TABLE IX.

Test Number.	Description of Treatment.	Elongation and Shrinkage.	Strength.	Total Deflection.	Total Carbon.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphor.	Sulphur.	Manganese.
	Not annealed...........	.155	425	.275	3.77	3.32	.45	1.78	.505	.041	.568
	Annealed by heat......	.096	400	.350	3.77	3.68	.09	1.78	.510	.043	.568
a	Difference	.059	−25	.025	0	.36	−.36	0	.005	.002	0
788	First of heat...........	.163	390	.22	2.910	2.28	.63	3.22	1.025	.123	.49
791	Last of heat............	.121	400	.22	2.950	2.47	.48	3.14	1.055	.100	.47
b	Difference	.042	10	0	.040	.19	−.15	−.08	.030	−.023	−.02
780	1st bars from one ladle.	.123	440	.23	......	....	......	3.52	......	.081	......
782	3d " " " .	.131	530	.27	......	....	......	3.52	......	.080	......
b	Difference	.008	90	.04	......	....	......	0	......	.001	......
784	1st bars from one ladle.	.143	400	.23	......	....	......	3.46	......	.079	......
787	4th " " " .	.136	500	.25	......	....	......	3.45	......	.083	......
b	Difference	.007	100	.02	......	....	......	−.01	......	.004	......
	No. 1 Bar One pair....	......	412	......	3.09	2.99	.10	3.79	......	......	......
	No. 2 Bar Same gate..	......	550	......	3.12	3.02	.10	3.84	......	......	......
a	Difference	......	148	......	.03	.03	0	.05	......	......	......
May 26	Original not tumbled...	.119	365	at 300 .170	3.20	3.05	.15	3.99	1.168	.078	.398
May 26	Tumbled 2 hours.......	.118	420	.175	3.33	3.16	.17	......	......	......	......
c	Difference	−.001	55	.005	.13	.11	.02	......	......	......	......
May 27	Original not tumbled...	.131	495	.140	3.24	3.06	.18	3.97	1.257	.081	.411
May 27	Tumbled 2 hours... ...	.128	547	.135	3.35	3.18	.17	4.03	1.288	.081	.398
c	Difference	.003	52	−.005	.11	.12	−.01	.06	.031	0	−.013
Dunn	Original not tumbled...	......	448	.1175	3.55	2.81	.74	2.05	.558	.074	.400
Dunn	Tumbled 2 hours.......	......	570	.1200	3.58	2.82	.76	......	......	......	......
c	Difference	......	112	.0025	.03	.01	.02	......	......	......	......
May 27	Same as above	......	......	......	3.24	3.06	.18	......	......	......	......
May 27	½ same original bar tumbled 6 hours......	......	......	......	3.27	3.10	.17	......	......	......	......
c	Difference	......	......	......	.03	.04	−.01	......	......	......	......

Determinations by *a*, E. E. Klooz ; *b*, Cary & Moore ; *c*, Dickman & Mackenzie.

proved that the increase of strength by tumbling is partly caused by a removal of the roughness on the surface of the casting, and by rubbing off all notches in the corners of the test bars.

I called the attention of Messrs. Dickman & Mackenzie, chemists, 1224 Rookery Building, Chicago, to the statement of Mr. Outerbridge, that chemical analysis of tumbled bars did not show any change in composition, and suggested that they should find if this statement was true, and that to do so would require the most

careful analytical work that could be done. They at once undertook the work, with results shown in Tables IX. to XIV. Regarding the determinations, Mr. Mackenzie writes: "I am frank to say that in all cases where total carbon shows an increase after tumbling, I am disposed to credit the same to the personal error of chemical analysis, since there can be no creation of carbon in the bar, but merely a rearrangement of molecular structure which should not affect the total, but may affect merely the proportionate amounts of the two carbons."

CHEMICAL COMPOSITION AND IMPACT.

Aside from the question of the relation of strength to the chemical composition, which is referred to later, the large number of records of pig-irons will allow a comparison of the increased strength by tumbling test bars with their chemical composition. The white and mottled samples did not show any flaw in the fracture, but it is hardly likely that any treatment influenced the strength of any of these bars. The tumbled (No. 2) bars of these two irons would probably have broken at the same load if they had not been treated. Regarding the Iroquois, Hinkle, Southern, and Bretting bars, there were two or three of each set of these bars left from the tests made in 1894 for the Committee of Tests of the American Society of Mechanical Engineers. These bars were all tumbled two hours, and the averages of the strength are shown as "tumbled"

TABLE X.

Pig-Iron.	Series 39. Protected by Sheet Iron.				Series 41. Struck 5,000 Blows.				Series 43. Foundry Castings. Averages for One Year.				
De Bardeleben.	Decrease in Length.	Original.	3 Hours Tumbled.	Difference.	Decrease in Length.	Original.	5,000 Blows.	Difference.	Average Shrinkage per Foot.	Average Elongation per Foot.	Original.	2 Hours Tumbled.	Difference.
White	–.00025	420	440	20	....	....	....	:...	170 to 160	......	381	422	41
Mottle	.....	370	380	10	–.00085	386	358	–28	160 to 150	......	372	397	26
No. 1 Foundry	–.00100	370	378	8	–.00325	350	355	5	150 to 140	......	367	403	36
" 1 Soft	–.00138	378	390	12	–.00418	424	406	–18	140 to 130	......	366	393	27
" 1 Silvery	–.00100	402	395	– 7	–.00431	353	365	12	Under 130	......	400	416	16
	Series 40.				Series 42.								
2 F. Woodward	–.00025	340	330	–10	–.00187	355	335	–20					
2 soft open. Rock-	–.00050	372	380	8	....	....	....	....					
2 " close. wood.	–.00075	330	365	35	....	....	....	....					
Close Silvery De Bar.	–.00025	228	220	– 8	–.00100	200	218	18					
Open " "	–.00125	400	390	–10	–.00088	406	390	–16					

The analyses of Series 44 also represent the composition of Series 39 and 41; and the composition of Series 40, 42, and 45 are alike.

TABLE XI.

Series 44 (a). De Bardeleben.	Elongation per Foot.	Original.	3 Hours Tumbled.	Difference.	Total Carbon.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphor.	Sulphur.	Manganese.
White	.00000	433	417	−16	2.01	.67	1.34	.94	.76	.42	.29
Mottle	.00094	371	363	− 8	2.74	1.00	1.74	1.36	.76	.06	.31
No. 1 Foundry	.00200	393	467	74	2.88	2.42	.46	2.53	.60	.04	.23
" 1 Soft	.00200	382	436	54	2.94	2.11	.83	3.65	.60	.06	.27
" 1 Silvery	.00212	370	382	12	2.17	1.60	.57	4.70	.59	.06	.27
Series 45 (b).											
2 F. Woodward	.00262	335	374	39	.....	.....	.50	1.006	.661	.017	.268
2 soft open } Rock-	.00162	362	391	29	.....	.....	.30	1.739	1.206	.017	.441
2 " close } wood.	.00137	347	390	43	.....	.....	.33	1.965	1.060	.027	.384
Close Silvery De Bar.	.00237	218	255	37	.....	.....	.40	4.702	.830	.107	.422
Open " "	.00350	375	402	27	.....	.....	.19	5.801	.884	.055	.316

Analysis by (*a*) Dr. W. B. Phillips, (*b*) T. S. Beeson.

TABLE XII.

Series 46. Dayton Pig-Iron.	Elongation per Foot in Inches.	Original.	2 Hours Tumbled.	Difference.	Total Carbon.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphor.	Sulphur.	Manganese.
No. 2 Mill	.00150	412	453	41	3.49	2.81	.68	.877	1.555	.0390	.284
Mottle	.00100	433	448	15	3.20	2.08	1.12	.882	1.792	.0420	.204
No. 2½ F dry	.00050	357	380	23	3.16	2.78	.38	1.310	1.482	.0200	.648
Open Bright	.00075	397	419	22	3.42	2.94	.48	1.531	1.535	.0236	.623
" "	.00000	378	403	25	3.51	3.11	.40	1.946	1.569	.0190	.389
No. 1 Mill	.00150	376	395	19	3.23	2.77	.46	2.040	1.457	.0271	.673
No. 2 F'dry	.00100	382	393	12	3.32	2.90	.42	2.290	1 567	.0227	.659
Open Silvery	.00250	453	451	− 2	3.26	3.08	.18	4.157	1.299	.0186	.511
Close Silvery	.00125	388	409	21	3.38	3.20	.18	4.349	1.544	.0180	.480

Analyses of carbons by Dickman & Mackenzie, other elements by Harry S. Fleming.

TABLE XIII.

Series 47.—Pig-Iron.	Elongation per Foot.	Original.	2 Hours Tumbled.	Difference.	Total Carbon.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphor.	Sulphur.	Manganese.
Buffalo No. 2, plain	......	443	344	1	2.99	2.61	.38	3.46	.33	.020	1.50
Buffalo No. 2	......	362	418	56	3.00	2.66	.34	3.64	.32	.020	1.50
Buffalo No. 1	......	386	401	15	3.10	2.75	.35	3.99	.34	.020	1.59
Licking No. B1	......	296	373	77	2.98	2.27	.71	3.74	2.33	.205	.44

Analysis of Buffalo by O. O. Landig; of Licking, Harry S. Fleming.

TABLE XIV.

Mixtures with Silicon Iron.	Elongation per Foot.	Original.	2 Hours Tumbled.	Difference.	Total Carbon.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphor.	Sulphur.	Manganese.
Series 48.											
Iroquois 1	.00100	289	337	48	3.82	2.36	1.46	.83	.211	.056	.35
" 2	.00125	339	364	25	3.90	3.20	.54	1.09	.273	.046	.31
" 3	.00200	389	403	14	3.69	3.21	.45	1.73	.270	.032	.50
" 4	.00250	427	422	−5	3.55	3.10	.48	2.13	.284	.045	.35
" 5	.00175	430	448	18	3.54	3.19	.16	2.42	.333	.017	.36
" 6	.00225	471	491	20	3.38	3.01	.38	2.74	.300	.034	.43
Series 49.											
Hinkle 7	.00200	338	374	36	4.02	2.78	1.24	.91	201	.029	.47
" 8	.00200	395	407	12	3.84	3.17	.67	1.16	.164	.015	.37
" 9	.00225	329	351	22	3.81	3.28	.53	.93	.258	.015	.48
" 10	.00250	439	444	5	3.20	2.91	.29	2.84	.211	.021	.63
" 11	.00200	443	504	61	3.32	3.00	.32	2.56	.264	.030	.58
" 12	.00200	456	440	−16	3.34	3.07	.27	2.77	.301	.031	.59
Series 50.											
Southern 14	.00150	378	394	16	3.15	2.89	.26	2.70	.809	.093	.59
" 15	.00200	427	443	16	3.13	3.03	.10	3.29	.980	.088	.50
Series 51.											
Bretting 16	.00200	378	424	46	3.56	2.70	.86	1.86	.309	.025	.57

Analysis by Dickman & Mackenzie, 1224 Rookery Building, Chicago.

in the table. The strength shown as "original" is the average of nine or more bars tested in 1894. The records are not therefore of bars cast in pairs from one gate. In the Dayton series the six bars were each cast from its own gate, and in different flasks, but bars of each iron were all out of one crucible. The bars had been in my testing room for ten years. Three bars of each iron were taken as original, and three were tumbled two hours. These records are not as directly comparable as if they had been made from bars cast in pairs. If bars had been cast in pairs, there would probably have been no cases where a loss of strength is shown. The series which has been kept ten years show that tumbling influences old castings the same as new. The test bars for Tables XI. and XII. were cast in pairs for this paper, and the records of bars tumbled three hours, Table XI., is the average of two pairs of bars in each case. The record of protected bars, tumbled three hours, Table X., is of one pair of bars of each kind of iron. The record of bars receiving 5,000 blows, Table X., is the average of two pairs of bars in each case.

The records of Series 43, Table X., were of bars made during a year and tumbled, and those having the same shrinkage were grouped. The highest shrinkage indicates least silicon. Taken as a whole, these records indicate that—

Test Bars of Gray Iron Containing Least Silicon Gain Most by the Process of Tumbling.

Such iron takes a closer copy of the mould, while iron containing more silicon does not burn into the sand as much, and therefore makes a smoother surface.

In half-inch bars from any one mixture, up to 3.50 per cent. of silicon, each increase of silicon generally adds to strength. The surface being already smoother, the proportionate gain in strength by smoothing during tumbling is not as great as with bars containing less silicon, which have a rougher surface to begin with. The bars which were protected, Table X., were smoothed somewhat, but not anything like as much as when unprotected. The test bars which received 5,000 blows on the end were not smoothed, and show no gain in strength.

I am not able to discover any relation between the chemical composition and the gain in strength except as it affects the roughness or the softness of the surface. Mr. T. S. Beeson, chemist at Niles Tool Works, Hamilton, Ohio, very kindly volunteered to make analyses of the series of five pig-irons, Series 45. All of these chemists deserve the thanks of those interested in cast iron, for the immense amount of work that they have been willing to do in the interest of original research. This paper would lose much of its interest if it lacked their contribution.

I also asked Messrs. Dickman & Mackenzie to ascertain—

What Chemical Change will Account for the Difference in Strength between Test Bars not Tumbled?

Although this question has nothing to do with impact, yet it is a vital question to those who are inquiring whether chemical or mechanical analysis is best able to account for physical changes.

The mixture from which the test bars of May 26th and 27th, Table IX., were made, was an all pig mixture except 5 per cent. of stove-plate scrap, and was the same so far as the eye could

tell, and had been running for eighteen days. The analyses of both were made as carefully as was possible, and show no difference in chemical composition. The grain of the bars of May 26th was open and coarse, while the grain of the bars of May 27th was fine and close.

As this question is of great interest, especially to chemists, and as it is a rare thing to have records of as many irons with complete chemical and mechanical analyses, I have made the collection still more complete by reproducing the first records in Table IX. I also asked Messrs. Dickman & Mackenzie to find a cause for the strength of the Dunn test bars. Mr. Wm. Dunn, of Canastota, N. Y., sent these bars to me. He said he used 2,000 pounds of a pig-iron having analysis: G. C. 3,30. C. C. 0,19. Si. 2,37. P. 0,487. S. 0,028. Mn. 0,48; also 1,300 pounds of stove-plate scrap. He did not send an analysis of this scrap, but I have the following analysis of Albany stove plate, made nine years ago, which would probably fairly represent his scrap: G.C. 2,846. C.C. 0,311. Si.2,90. P.1,027. S. 0,054. Mn. 0,252. He also uses 700 pounds of his own scrap, which would be represented by the Dunn analysis of Table IX. We can roughly calculate what the chemical composition of his castings should be. To be safe, I took the silicon of the stove-plate scrap as 2,75. Messrs. Dickman & Mackenzie calculate that his mixture should contain G.C. 3.15, C.C. 0.279, Si. 2.39, P. 0.665, S. 0.38, Mn. 0.421. The total carbon calculated would be 3.39, and analysis showed 3.55, a gain of 0.121. The silicon in the casting is 0.61, or 25 per cent. less than it should be by this calculation. The P. in the casting was 24 per cent. less than it should be. Some chemists claim that the elements in a casting can be calculated from the elements put in the cupola. By this method it would seem that Mr. Dunn had added from 10 to 25 per cent. of steel scrap in the cupola. The appearance of the fracture of the test bar suggested this. I have received no reply to my question as to whether steel scrap was added. The addition of steel scrap will, in almost every case, increase the strength as much as in this case, while pig-iron, with exactly the same analysis, will not give as strong castings. In other words, the increase in strength is not due to the chemical change, but apparently to a mechanical mixture of the pure iron with the cast iron.

TESTS OF BARS ONE INCH SQUARE.

The following tests by Prof. J. B. Johnson, of Washington University, St. Louis, did not arrive in time for insertion after Table VI. The pair of bars No. 1 was made early, and No. 2 late, the same day; Nos. 3 and 4 the next day, and so on.

TABLE XV.

RESULTS OF TESTS ON 28 CAST IRON-BARS LOADED IN THE CENTRE ON SUPPORTS 13 INCHES APART.

Bar No.		Treatment.	Cross Section.	Breaking Load.	Final Defl.	Modulus of Rupture.	Modulus of Elasticity.	Resilience in lbs. per cu. in.
1	9,000 blows.	Normal	$h=1.027$ $b=1.021$	2,110	0.11	38,270	10,700,000	8.80
		Jarred	$h=1.030$ $b=1.024$	2,400	0.14	43,170	9,550,000	13.00
2		Normal	$h=1.037$ $b=1.031$	2,380	0.153	42,000	7,750,000	12.835
		Jarred	$h=1.037$ $b=1.050$	2,200	0.154	39,200	7,250,000	11.985
3		Normal	$h=1.014$ $b=1.027$	2,310	0.136	42,700	10,100,000	12.500
		Jarred	$h=1.006$ $b=1.011$	23.44	0.139	44,680	8,950,000	11.68
4		Normal	$h=1.035$ $b=1.026$	2,244	0.152	39,920	8,200,000	12.40
		Jarred	$h=1.018$ $b=1.021$	2,126	0.141	39,220	9,700,000	11.00
5	18,000 blows.	Normal	$h=1.025$ $b=1.029$	2,144	0.162	38,750	7,300,000	13.30
		Jarred	$h=1.025$ $b=1.032$	2,156	0.177	38,850	7,180,000	15.40
6		Normal	$h=1.037$ $b=1.035$	2,352	0.162	41,360	7,900,000	14.60
		Jarred	$h=1.040$ $b=1.020$	2,338	0.162	41,080	7,500,000	14.10
7		Normal	$h=1.022$ $b=1.021$	1,942	0.148	35,560	7,310,000	11.40
		Jarred	$h=1.023$ $b=1.022$	2,150	0.160	39,250	7,850,000	13.90
8		Normal	$h=1.032$ $b=1.040$	2,294	0.164	40,387	7,570,000	14.50
		Jarred	$h=1.023$ $b=1.019$	2,232	0.164	40,811	7,860,000	14.40
9	Tumbled 3 hours.	Normal	$h=1.027$ $b=1.030$	2,360	0.145	42,356	8,750,000	13.00
		Tumbled	$h=1.027$ $b=1.030$	2,490	0.152	43,235	8,470,000	14.20
10		Normal	$h=1.028$ $b=1.027$	2,400	0.142	43,120	8,850,000	10.50
		Tumbled	$h=1.022$ $b=1.020$	2,580	0.158	47,235	8,900,000	15.10
11		Normal	$h=1.027$ $b=1.031$	2,138	0.124	38,355	8,915,000	9.88
		Tumbled	$h=1.024$ $b=1.018$	2,355	0.138	42,690	9,394,000	12.80
12		Normal	$h=1.029$ $b=1.037$	2,200	0.128	39,320	8,900,000	10.20
		Tumbled	$h=1.026$ $b=1.031$	2,390	0.153	41,425	7,750,000	13.50
13	Tumbled 6 hours.	Normal	$h=1.020$ $b=1.007$	2,302	0.137	42,890	9,200,000	16.20
		Tumbled	$h=1.007$ $b=1.011$	2,094	0.135	39,815	8,770,000	11.40
14		Normal	$h=1.032$ $b=1.029$	2,462	0.187	43.800	7,300,000	18.10
		Tumbled	$h=1.030$ $b=1.023$	2,400	0.186	43,950	7,750,000	18.40

TABLE XVI.

	Breaking Load—Bars, 1-Inch Square Supports, 12 Inches Apart.				Breaking Load—½-Inch Square Section of 1-Inch Bars 12 Inches Long.			
	Original.		Treated.	Difference.	Original.		Treated.	Difference.
1	2,282	9,000 blows.	2,585	303	285	9,000 blows.	323	38
2	2,563		2,434	−129	320		304	−16
3	2,487		2,524	37	311		316	5
4	2,417		2,289	−128	302		286	−16
	2,437		2,458	21	304		307	3
5	2,309	18,000 blows.	2,322	13	288	18,000 blows.	290	2
6	2,533		2,517	−16	317		315	−2
7	2,091		2,315	224	261		289	28
8	2,470		2,404	−66	308		300	−8
	2,351		2,392	41	294		299	5
9	2,542	Tumbled 3 hours.	2,682	140	318	Tumbled 3 hours.	335	17
10	2,585		2,778	193	323		347	24
11	2,302		2,536	234	288		317	29
12	2,370		2,574	204	296		322	26
	2,450		2,643	193	306		330	24
13	2,479	Tumbl'd 6 hours.	2,255	−224	310	Tumbl'd 6 hours.	282	−28
14	2,651		2,585	−66	331		323	−8
	2,565		2,420	−145	320		302	−18

Table XV. shows the records of bars sent to Professor Johnson. In Table XVI. the loads are calculated for supports 12 inches apart, and the loads for a ½-inch square section of each bar are calculated, to allow comparison with preceding tables.

The strength of a ½-inch square section of a 1-inch square test bar is not nearly as strong as a test bar cast ½ inch square from the same iron, because the slower cooling of a large casting increases the size of the grains, which decreases strength. (See *Transactions*, vol. xvii., pp. 685 and 717.) Professor Johnson says: "We have observed the effect of blows endwise on the length of two bars 1 inch square and 50 inches long (measured with micrometer), and find that a single blow shortens the specimen very slightly, but the results are discordant."

In many of my tests a number of blows would shorten a bar, a like number might make any change, or else a part of the previous shortening might be lost, but the general tendency was a shortening, though the total amount in any case was very small.

FRACTURE BY SHOCK.

This paper does not bear upon this subject at all. Resistance to fracture depends upon the cohesion and interlocking of grains and upon the brittleness of the metal. The shock here considered does not change the form of the test bar, and was not sufficient to produce fracture. This paper measures the influence of simple shock by tests of dead load.

If a load be gradually applied transversely to a test bar, it will deflect the centre of the bar a certain distance. If the same load is suddenly applied to the same bar, it will deflect the bar twice as much, and if it is not fractured, the test bar will spring back, carrying the load with it, and after ceasing to vibrate will settle with the load at the point which it would have reached with the load gradually applied. Partially viscous bodies, if not too hard, will not break by a force slowly applied, but if bent suddenly will break. Cast-iron takes set at each increase of dead load. How far each grade of iron will resist a load suddenly applied must be determined by a test of each iron. This subject has received very little attention. The general principles of impact are treated very fully in "The Materials of Construction," by Prof. J. B. Johnson.

DISCUSSION.

Mr. William Kent.—It seems to me that these phenomena of increasing the strength of cast iron by peening it or hammering it, are all of the same nature as the phenomena shown in increasing the strength of nearly all metals by any change whatever in the position of the molecules, if that change is slight; that is, wire-drawing, cold rolling, cold hammering, bending, twisting—all these motions will increase the strength and the hardness and decrease the ductility of all metals, so far as I know; certainly brass, copper, steel, iron. They are thus made stiffer, so that it is not unreasonable to suppose that the same phenomena would happen with cast iron, provided the pulling apart of the molecules is not too great. If you hammer a piece of iron it appears that you will increase its strength. If you hammer it too long, or too hard, you will break it. In the same way in drawing wire: if you draw it just enough, you will improve its strength; if too much, you will make it brittle.

Mr. Strickland L. Kneass.—This paper by Mr. Keep certainly

shows a commendable amount of industry, but it is doubtful if it can be regarded as a final contribution to the literature on the "Behavior of Cast Iron Under Impact." Even a hasty reading gives the impression that the author is not sure of his ground, while it is obvious that his theorems are not always proved, nor his material thoroughly digested. The line of his experiments would seem to be too narrow to allow the validity of his general conclusions, while others are based on measurements of rough castings, from which a deviation of from $\frac{1}{10,000}$ to $\frac{8}{10,000}$ inch would entirely upset his deductions. Several contradictions occur, one of the most unfortunate for the author's theory being on page 354, line three, where he states that of eleven test bars in Series *m*, six had grown shorter, four were unchanged, and *one* had grown longer, while on page 358, last paragraph, "All tumbled bars reported in this paper were measured, and gained in length. The gains of a number of bars are given in Table III., Series *m*, showing the gain at the end of each half hour, etc.," so the reader is left in doubt as to the facts, and it is impossible to discuss intelligently this part of his paper or the appended tables. Another table containing some very interesting statements, if true, is the last part of IX., where the author shows that the effect of tumbling is to increase the *total carbon*, in one case as much as 0.13. This statement is so extraordinary that it would require many more experiments than given, to prove that the total quantity of one of the constituent elements of cast iron could be changed by mechanical manipulation; yet, if these tables are incorrect, no strength is added to the confidence in the accuracy of the figures in the other tables.

Referring to the more important part of the paper, the following theorem is noted. "The strength gained by tumbling is due to making the surface of the test bar smooth, and to condensing the surface by peening."

This is apparently laid down as a general law, and is stated as proved. There is no doubt that tumbling increases the transverse strength; but the author's conclusion cannot be accepted entirely. Table VII. indicates a gain in strength in all the series in which the bars were pounded; namely, 27, 29, 30, and 31. If a bar be of the same cross-section, and homogeneous, it would necessarily break at the centre under these transverse tests, and if peening produces the increase in strength, it would have to be done at the centre to obtain any gain. But here, no matter where

the bar is treated, there is an increase in transverse strength. Further, according to the author's theorem, end blows would not produce this effect. His own Table V. proves that they do have some influence, although, of course, not as great as tumbling. Taking the average of the Series 9 to 17 inclusive, where the bars were treated with 3,000 blows and over, there is a gain of seven pounds. It is true that the effect of side blows upon soft iron bars is to peen the surface and to increase the strength; but it is the contention of the writer that this is not the sole cause, and that Mr. Keep's own tests show the fallacy of his theorem. In a paper read before the American Society of Mining Engineers, in 1896, Mr. A. E. Outerbridge gives the results of a large number of experiments with cast-iron bars, one inch square, subjected to side and also to end blows; he found the effect was the same in both cases. Subsequently the Franklin Institute made a special examination of the subject, and in a report, which corroborated the results obtained by Mr. Outerbridge in his original experiments, agreed with him in his theory as to the probable reason for the increase in strength due to tumbling. Through the courtesy of Dr. Wahl, Secretary of the Franklin Institute, the writer was given access to this special report, and is permitted to state that the average gain in transverse strength of ninety-two bars over their companion bars, due to tumbling, was over 18 per cent. The theory advanced by Mr. Outerbridge to account for his observations was that of the "Mobility of the Molecules of Cast Iron" at ordinary temperatures, and that the increase of strength is due to relief of internal strains, due to vibration. These vibrations may be produced by tumbling, by end or side blows, or in any manner desired. The tests made by Mr. Keep were made with bars of one-quarter the sectional area, although of the same length as those used in Mr. Outerbridge's tests, and it is possible that this, as well as the entirely different quality of irons used, would account for the comparatively small effect produced by end blows in Mr. Keep's apparatus. The former used ordinary foundry iron; Mr. Keep probably stove-plate iron, containing twice as much silicon. It seems, therefore, that the author's experiments were carried on in too narrow lines to justify his generalized theorem as cited above, and his own tests seem to be best accounted for by the more scientific theory.

Mr. Thos. D. West.—On the third page of Mr. Keep's interesting paper he says: "It is difficult to determine whether the

shortening which follows an end blow is caused by general re-arrangement of crystals or by an upsetting of some portion of the bar. If the latter, cast iron is upset by a very slight blow."

Experienced founders know that cast iron can be readily upset. Many utilize this quality to disguise cracks in castings. This is done not only with cast iron, but with steel as well. Castings which would have been condemned on account of cracks, could the engineer or inspector have seen them, have been closed up so neatly, by means of peening, that the man doing the job could not readily tell where the crack was from appearances. It is a common thing in founding to flatten out spots or portions of a gray iron casting. The softer the iron, the more readily such is done. The blows which shorten a piece of iron can, by tact in peening, also lengthen it. Crooked castings are often straightened out by founders by merely peening the concave surface. The two elements just cited illustrate the principle involved, permitting Mr. Keep to lengthen or shorten thin bodies of cast iron.

The last two lines on page 354 say: "If further experiment should show that the casting becomes shorter when struck with a hammer, it will in part explain the frequent cracking of castings by rapping off the gates, as in the case of a pulley with light arms. If a blow exerts this influence, we can understand the frequent change in shape of many castings." The writer's views on this point are that the cause of the cracking of pulley castings, etc., is not of any change in length created by reason of rappings, but the difference of proportions in castings causing unequal contraction of its parts, which, when jarred by a blow, causes the part stretched or held in union by strains to separate, thus giving us our cracked castings. This is a quality often proved by changes in the temperature of the atmosphere, causing castings to crack of their own accord which had never received blows of any description.

On page 375 Mr. Keep says: "In half-inch bars from any one mixture, up to 3.50 per cent. of silicon, each increase of silicon generally adds to strength." If this means anything at all, it asserts that a half-inch square bar will define the strength of any or all grades of iron and make the result to agree with the actual results found in testing strengths by tensile strain, hydraulic pressures, etc. The writer has never seen a series of tests with half-inch bars, ranging through the different grades of iron (or even in one grade alone), that showed a uniform increase in strength

from the weakest to the strongest iron, which has been displayed by bars of larger size. To illustrate this quality more forcibly, the following table is presented.

TRANSVERSE AND TENSILE TESTS OF SPECIALTY MIXTURES.

Specialty of Mixture.	Transverse Strength 1⅛ Round Bars.	Tensile Strength 1⅛ Round Bars.	Transverse Strength ½ Square Bars.
	Pounds.	Pounds.	Pounds.
Gun Metal	3,686	37,100	398
Chill Roll	2,980	30,100	265
Heavy Machinery	2,657	28,676	395
Car Wheel	2,553	23,270	277
Light Machinery	1,931	21,120	454
Stove Plate	1,798	17,150	160
Sash Weight	1,406	7,125	167

A study of this table shows the half-inch bars very erratic, and bearing little relation to the uniformity in the increase of strength exhibited by the 1⅛-inch round bars. The transverse tests were obtained from bars tested 12 inches between supports. All tests here given are from solid bars, and are taken from a series of 100 tests, which the writer presented in a paper on "Specialty Mixtures," about two years ago, to the W. F. A. The test bars were cast by some of our leading foundries and tested by authorities in such a manner that the figures presented can be supported as reliable. The transverse and tensile strengths of the 1⅛-inch round bar will be found a most excellent guide for any desiring coefficients for figuring the strength of cast iron in its various grades as coming from practical founding. The table also exhibits what the writer claims is the most practical way to conduct a series of tests, to define the fitness of any size of form of a test bar so as to most truly tell us the strength of cast iron. The reason for half-inch square bars being so erratic in recording the strength of cast iron is due to the fact that such small bodies of iron, when cast in green sand moulds, have the state of the carbon and the physical qualities too easily affected or changed by differences in the "temper" of moulding sands and the metal's degree of fluidity at the time moulds are poured. We have but to refer to Mr. Keep's own paper to prove that light bodies, as of half-inch square bars, are radically affected by variations in the "temper" (dampness) of sand and the fluidity of metal.

On page 367, Table VIII., is shown that with the same ladle of

iron there are differences owing to variations due to the fluidity of metal amounting to 65, 86, and 68 pounds in half-inch bars possessing an average strength of 381 pounds. This means that in the pouring of two different heats we can have an error, in recording strengths, of what may be truly the same mixture, or grade of iron, of nearly 20 per cent. Carrying this up to one-inch square bars, should they be as erratic as half-inch bars, we would have the same mixture or grade of an iron to be about 2,500 one day and 3,000 the next, presenting an error of 500 pounds from what is the actual condition. The writer knows from research that such a difference does not exist with round bars one inch square in area, or over, and could point to experiments which he has made with variations in fluidity of metal to prove that test bars, as large as one inch square in area, when cast in the round form especially, show very little difference. In the square form, on account of their having corners to chill, a difference of 5 per cent. may in some cases be found. At the ninth line from the bottom, page 367, Mr. Keep says: "I have proved before that iron last poured from a ladle will make stronger test bars than the iron poured first." The writer has found the reverse results as well as that noted by Mr. Keep, but would say it is dependent upon the grade of iron we are using, and the size of the test specimen in causing the iron to vary in the carbon to be graphitic or combined, that controls the quality of test bars being stronger or weaker with the last pour from a ladle.

Any one who is familiar with founding knows that, as a rule, in the same shop, no two days will find the fluidity of the metal exactly the same, saying nothing about the great difference that must exist between different shops, and which can be such as to cause a wider difference in the strength of test bars in the same mixture than Mr. Keep's figures show. Any giving this subject study can readily see the wisdom of using test bars that are the least apt to be affected by changes in the fluidity of metal, whether for one's own shop's record or for comparison with others. The evils of irregularity in the fluidity of metal, it is to be remembered, are not all that is detrimental to small test bars in the matter of correctly recording the strength of iron. When we consider that slight variations in the nature and "temper" of moulding sand are also as bad in their influence to cause small test bars to be erratic, both combined are certainly qualities not to be ignored by any one desirous of adopting what is best to most truly record the strength of cast iron.

The writer wishes it understood that he is not questioning Mr. Keep's tests on shortening or lengthening bodies of iron, or those embodying increased strength by tumbling (a discovery first made by Mr. Outerbridge), where test bars are used in pairs, for comparative purposes. Mr. Keep's test in this line with half-inch bars is a wholly different affair from that which he would have the tenth and eleventh line on page 375 cover, and which implies that a half-inch bar will correctly test the strength of cast iron for the general purpose test bars are used for. There are several other points which the writer would like to discuss, but will have to forego at present, as he fears that what he has written has overstepped the time allotted for discussion.

*Mr. Keep.**—In describing his discovery that tumbling castings cause an increase of strength, Mr. Outerbridge, in his paper, already referred to, states that rectangular test bars are weakened by the strains caused by the difference in cooling of the metal near the surface and of that nearer the centre, and that the grains at the surface are in an *overcrowded* condition. He seems to think that any kind of shock allows these crowded grains to assume a less crowded arrangement.

When melted iron fills a mould the portion next the surface becomes solid within a few seconds, while the central portion is still fluid. The crystals form with perfect freedom and regularity over the whole surface, because there is no compression in any direction.

As they cool each crystal becomes slightly smaller, causing the whole casting to be smaller. This shrinkage can cause no crowding among the grains at the surface, but rather a pulling apart from each other. When the surface has become rigid the central melted portion crystallizes more slowly and forms larger grains, but as each grain cools it grows smaller and tends to pull from those next to it. Sometimes there are not enough crystals to fill the space, and a spongy spot results. There is never any crowding. On account of each crystal trying to pull its neighbor the influence of a shock is to cause all crystals to drop closer together, and cause a shortening of the whole casting.

The lengthening of a test bar by tumbling is caused by the pounding on the sides, which crowds the crystals together and towards the centre and causes a general flow endwise. The test bar decreases in thickness and increases in length.

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* Author's closure, under the Rules.

It may seem to be a contradiction when I stated that after tumbling eleven test bars half an hour, six bars had grown shorter, four were unchanged, and one had grown longer.

Instead, it shows that the shocks imparted during the first part of the half hour shortened *all* of the eleven bars, and that afterward the peening of the surface had begun to lengthen *all* of the bars. At the end of the half hour the case stood as stated: six bars were shorter than when placed in the tumbler, the lengthening not having yet equalled the previous shortening. Four of the bars had been lengthened so much as to entirely overcome the shortening, and one bar had not only been peened enough to regain its original length, but had been stretched beyond its original length. Continued tumbling afterwards lengthened all of the bars.

The pulling apart of a casting having reëntrant angles or variation in the size of its parts, is caused by the same pulling of the grains together. In time these grains generally adjust themselves without causing fracture. In castings of uniform section, like a square test bar, no such tendency to pull apart can exist.

Series 23 of Table VI. gives the average of the strength of bars tested by the Committee of the Franklin Institute. These tests, like all in this paper, prove that tumbling strengthens castings, but the committee endorsed Mr. Outerbridge's theory of the crowded state of crystals, and of the mobility of molecules as a cause for the gain in strength, without reporting any tests of bars pounded on end, or tests to ascertain whether the smoothing and pounding the surface of a test bar in the tumbler exerted any influence on its strength.

It seems to me that the experiments described in this paper prove:

That the smoothing and hammering of the surface of a casting by tumbling is the cause for the greater part of the gain in strength.

That shock causes a shortening of a casting by allowing the grains to settle closer together.

That while repeated shocks, like blows from a hand hammer, may very slightly increase strength by this release of strain between crystals, yet the gain is not enough to make shock a practical method for strengthening castings; and if there are reëntrant angles, or variation in size of parts, a very slight shock might cause fracture, while if the casting were allowed to rest for a time, it would not break.

DCCLXVII.*

AN ACCURATE COST-KEEPING SYSTEM.

BY H. M. NORRIS, CINCINNATI, O.
(Junior Member of the Society.)

OF all the troublesome and knotty problems connected with economical shop management there are few quite so puzzling to the engineer as that of accurate cost keeping. Hundreds of systems have been invented and put into practice, some of which possess a number of points of merit; but the ideal system, such as is sought by all our large concerns, remains yet to be discovered. One manufacturer figures fifty cents per hour on all classes of work, irrespective of the machine or class of labor employed; another charges thirty-five cents per hour for boys' time and forty-five cents per hour for men's time; others add a fixed percentage to the sum of the cost of labor and material—the percentage in ninety-nine cases out of a hundred being based upon the amount Smith and Jones use, or, what is almost as bad, upon the expenses of some one preceding year—all of which is bad practice, and denotes inefficient shop management.

A cost-keeping system to be of real value must forever eliminate all guesswork, and be so designed that it will give accurate results under all conditions of business. To determine the cost of any article of manufacture, it is necessary to *know* three things: the actual cost of labor, the actual cost of material, and the actual cost of running expenses. The first two items are easily found, but how to get the third, at the minimum cost, is the problem, and one not easily answered; although the writer feels that the system about to be described is a step in the right direction.

Upon the receipt of an order at the main office, it is given a number and entered in the order book in the usual manner,

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* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

after which duplicate orders are issued to the several foremen. As the work is taken in hand, the workmen in each department charge their time upon a different colored time card, the one for use in the machine shop being printed in the form shown in Fig. 85. At the close of the day these slips are collected and handed to the foreman, who, after assuring himself that the charges are correct, turns them over to the office, where the time clerk assorts them in reference to the workmen's numbers and enters the total time made by each on that date in the pay-

Fig. 85.

TIME CARD.

Symbol *6 A 2* No. pcs. *6* Shop No. *1788*

Name *Jacob Kerr* No. *142* Date *8—12—'97.*

Turning *4*	Boring	Milling
Planing	Chucking	Scraping
Shaping	Cutting off	Assembling
Drilling	Grind and Pol.	Painting

Commenced *8* Finished *12* Hrs. *4* Amt.

roll book, after which he fills in the "amounts" either calculated by the slide-rule or taken from a table which is easily to be computed once for all. The tickets are then assorted with regard to shop number; and the total number of hours worked that day in each department—the latter being denoted by the color of the card—together with the actual cost of wages paid or due on the same, and of the material used, as figured from the stock slip, Fig. 86, are entered in the daily labor and stock account book, a portion of a page of which is shown in Fig. 87. This book is ruled for the several days of the week, each line showing the actual cost of its order number for that day, and is footed up at the close of the week, thus making it an easy matter to get

at the total cost of any job, at all times, with a minimum amount of labor—the hourly burden or average ratio existing between productive labor and general expense being known.

The term "general expense" is meant to include every outlay of whatever nature which is not chargeable to some specific order number, and comprises eighteen distinct charges, as shown in Fig. 88.

FIG. 86.

STOCK SLIP. DATE *8—24—'97.*

ORDER.	MATERIAL.	@	AMOUNT.	
1788	*24 lbs. Machy. Steel*	*3½*		*84*
"	*158 " Cast Iron*	*2*	*3*	*16*
1789	*200 " " "*	"	*4*	*00*

A includes all labor in draughting-room not chargeable to some specific order number.

B, all pattern work on the regular line of standard tools, or other work not chargeable to a specific order number.

C, all printed matter, office fixtures, stationery, drawing-paper, and other supplies used in either office.

D, all oils, waste, emery cloth, paint, nails, lumber, or other supplies used throughout the shop.

E, all productive labor upon work which is salable.

F, all productive labor, all material, and all bills for merchandise which form a part of the cost of such new tools as files, drills, monkey wrenches, oil cans, reamers, mandrels, milling cutters, etc., which may be classed as perishable.

G, all productive labor, materials, and bills pertaining to new non-perishable tools, such as machinery, jigs, and fixtures.

H, all productive labor, materials, and bills chargeable to the maintenance of perishable or non-perishable tools.

FIG. 87.

DAILY LABOR AND STOCK ACCOUNT.

Month of August, 1897.

Order Number.	Date.	Drawing-Room.		Pattern Shop.		Foundry.		Machine Shop.		Total.	Stock.	Remarks.
		Hrs.	Am't.	Hrs.	Am't.	Hrs.	Am't.	Hrs.	Am't.	Am't.	Am't.	
1788 26/33	23											
	24	....	......	....	......	....	......	5	$0 45	......	$4 00	
	25	....	......	....	......	....	......	10	1 60			
	26	....	......	....	......	....	......	12	3 00			
	27	....	......	....	......	....	......	10	1 20			
	28	....	......	....	......	....	......	23	5 75			
Totals	..	....	......	....	......	....	......	60	$12 00	......	$4 00	
1789 26/34	23	....	......	....	......	....	......	50	$9 00			
	24	....	......	10	$2 50	....	......	60	10 80			
	25	....	......	....	......	....	......	60	10 80	......	$5 50	
	26	9	$3 60	....	......	....	$7 50	40	7 20			
	27	9	3 60	....	......	....	......	42	7 56			
	28	....	......	....	......	....	......	60	11 94			
Totals	..	18	$7 20	....	$2 50	....	$7 50	312	$57 30	......	$5 50	

R, all other items of expense not included in the letters from *I* to *Q*, such as wages of the foreman, time clerk, stenographer, and laborers; the erection of countershafts and cranes, the moving of old machinery, the building of foundations, and the setting up of new machinery.

S, all labor spent in replacing work which is condemned through bad workmanship or other causes.

With the exception of item *E*, which, of course, forms no part of the general expense, all labor chargeable to any of the above letters is described upon blue cards, printed as shown in Fig. 89, which are turned into the office daily with the regular slips, and

the cost of the same entered in the labor and stock account book, opposite their respective letters, in the same manner as the regular cards are charged to their respective order numbers.

At the end of the month the four or five, as the case may be, of total weekly charges against each letter are added together, and the sum placed opposite the corresponding letters on the distribution of charges blank, Fig. 88; analyzing which, we see that of the $4,680 paid out during the month, only $2,340 went into work for which there is any compensation. Further,

FIG. 88.*

DISTRIBUTION OF CHARGES FOR MONTH OF AUGUST.

A....	Drawing Office	$40 00
B....	Pattern Work	32 00
C....	Office Supplies	25 00
D....	Shop Supplies	286 00
E...	Labor	2,340 00
F....	Perishable Tools	175 00
G....	Non-Perishable Tools	30 00
H....	Maintenance of Tools	25 00
I....	Advertising	100 00
J....	Light and Heat	....
K....	Traveling Expenses	80 00
L....	Official Salaries	700 00
M....	Rent and Power	250 00
N....	Taxes	6 00
O....	Insurance	12 00
P....	Interest	75 00
Q...	Patents and Royalties	....
R....	General Expense	500 00
S....	Extras	4 00
T....	Total	$4,680 00

that the returns from this work must be sufficient to cover the $2,340 paid in wages, plus the sum of all the other outlays, amounting to $2,340 more = $E + 100$ per cent. of E. In other words, we must receive $2 for every dollar charged to productive labor before we so much as pay bare expenses. The question therefore is: How can we best determine the cost of the individual job so that the total receipts for the month's work will be double the cost of productive labor? Figuring on the basis of E plus a certain per cent. of E will not do, as it makes the charge for boys' time absurdly low, and good men's time far

* See subsequent arrangement, Fig. 93, designed after meeting, and described in vol. xxi., No. 8, *American Machinist.*

too high. Referring to our books, we see that the labor charge of $2,340 represents 11,700 hours' work. Dividing this time into the general expense item, $2,345, gives twenty cents as the cost per hour of running expenses. Multiplying the 11,700 hours by .20, and adding the actual cost of labor, $2,340, gives $4,680, or the same result obtained by increasing the $2,340 by 100 per cent., and at the same time eliminates the objections advanced against the latter plan, as illustrated in the following example, in which both methods are compared with the old "so-much-per-hour" plan:

3	hours	at .10	=	$.30
6	"	" .15	=	.90
9	"	" .20	=	1.80
12	"	" .25	=	3.00
30	hours			$6.00
	General expense,			6.00
	Actual cost,			$12.00

Col. 1.	Col. 2.	Col. 3.
3 × .40 = $1.20	.30 + 100% = $ .60	3 × .20 + .30 = $ .90
6 × .40 = 2.40	.90 + 100% = 1.80	6 × .20 + .90 = 2.10
9 × .40 = 3.60	1.80 + 100% = 3.60	9 × .20 + 1.80 = 3.60
12 × .40 = 4.80	3.00 + 100% = 6.00	12 × .20 + 3.00 = 5.40
$12.00	$12.00	$12.00

Suppose the total charge against a certain job amounted to $6, consuming thirty hours' time as above, and that the cost of running expenses for that length of time is $6 more, then $12 is the amount which we must receive for the work, exclusive of all profit. Figuring, first, on the old basis of a fixed charge per hour, Col. 1, we have $12 ÷ 30 = 40 cents as the rate per hour at which each item must be charged to net $12 on the job as a whole. Figuring, next, on the basis of "wages plus a certain percentage of wages," Col. 2, we have $6 ÷ $6 = 100 per cent. as the percentage by which each item of wages must be increased to meet general expense and net the $12 necessary to cover costs. Figuring, lastly, on "time multiplied by general expense per hour plus wages," Col. 3, we have $6 ÷ 30 = 20 cents as the amount per hour which must be added to each item of wages to make the $12. Comparing the last

two methods, the first being unworthy of this name, we note that while the second system of figuring accomplishes its mission so far as the ultimate results are concerned, it is manifestly inferior to the third plan, in which expenses are made on every hour of labor, irrespective of the rate per hour of the workman—the loss incurred on cheap labor by the second plan not having to be made good by overcharging for the work of those requiring greater skill.

Having thus assured ourselves of the practicability and superiority of the last-described method of determining costs

Fig. 89.

TIME CARD.

No. *176* Charge *R*

Name *John Smith* Date *8—7—'97.*

Time was put in on *Erecting counter-shaft for new style 25" Upright Drill.*

Commenced *7* Finished *9.30* Hrs. *2½* Amt.

from hours worked and wages paid, and that the general expense for the month is equivalent to a fixed charge of 20 cents per hour of productive labor, we are now prepared to calculate the cost of each individual job, the form of blank for which is illustrated in Fig. 90. The first column is filled in directly from the daily labor and stock account book, and comprises a complete list of all the orders worked on during the month. The column headed "Balance" represents the total cost of each order up to and including the last day of the preceding month, the items being copied from the column headed "Total" on that report. Turning to our account book, we find we have 1,246 hours, costing $210.50, together with $6.25

worth of stock, charged to order No. 1,785 last month. We enter the $210.50 under "Labor," the $6.25 under "Stock," and multiply the 1,246 hours by .20=$249.20, or the cost of running expenses chargeable to this order. Adding these four items together, we have $780 as the total cost of order No. 1,785 up to the beginning of the present month. If the work is finished, this amount is then carried to the next column, and the number dropped from the following month's report. On short jobs commenced and finished in the same month, all necessary figuring may be done in a few moments on the form shown in Fig. 91, in which the cost of each department is shown separately.

Judging by the length of the description, it may seem to some that this system is altogether too cumbersome to warrant its adoption in a large number of shops; but the fact of the matter is,

FIG. 90.

ANALYSIS OF COST OF PRODUCTION.

Month of August, 1897.

ORDER No.	Balance.	Labor.	Stock.	General Account.	Total.	Finished.	REMARKS.
1785	$314 05	$210 50	$6 25	$249 20	$780 00		
1786	117 50	126 25	10 10	130 00	383 85		
1787	225 00	600 00	325 00	625 00	1,775 00		
1788	....	12 00	4 00	12 00	28 00	$28 00	
1789	....	67 00	13 00	68 00	148 00		
1790	....	113 00	30 00	115 00	258 00	258 00	

that the daily book-keeping consumes not more than two hours' time per hundred men employed, and the extra labor at the end of the month is only a matter of a day, or a day and a half, at most, of one clerk's time.

At this writing the system has been in actual operation only a few months, but its advantages over all other systems of which the writer has any knowledge—and he has studied the question pretty thoroughly—has been so clearly demonstrated within that time that he feels no hesitancy in giving the plan his unqualified recommendation, barring a few minor changes in printed matter, such as inserting an extra line between each weekly division in the labor and stock account book, Fig. 87, for the carrying over of the total cost of the work to that week, so as to avoid the necessity of having to add up the weekly totals at the end of the month; adding an hour column under "Labor" on the "Analy-

sis" sheet, Fig. 90, and one under "Total," Fig. 87; although this last is hardly necessary, with the "Balance" line first mentioned.

In conclusion, it might be well to add, in anticipation of the possible criticism, that the system only furnishes data on a job as a whole, and not on the cost of the individual piece; that after the time is transferred from the cards to the account book, as described, the cards are filed away in pigeon-holes bearing the same number as the order; and upon completion of the same the tickets are again gone over and assorted with regard to the

FIG. 91.

COST STATEMENT.

Shop No........ *For........................* *Order No........*

WEEK ENDING.	DRAWING-ROOM.		PATTERNS.	CASTINGS.	STOCK.	MACHINE SHOP.	
	Hours.	Amount.	Amount.	Amount.	Amount.	Hours.	Amount.
Aug. 7	4½	$1.80	$71.75	$16.45	$13.20	7	$0.58
" 14	22¼	8.90	5.50	121.25	8.60	247	45.63
" 21	14¼	5.70	4.25	12.00	......	281	42.84
" 28	9	.10	......	......	......	228	31.63
Total....	50	$16.50	$81.50	$149.70	$21.80	763	$120.68

Drawing-Room Time	50	General Expense..............	$213.25
Machine-Shop Time	763	Drawings......................	16.50
Total Time...............	813	Patterns..	81.50
Hourly Burden...............	.25	Castings......................	149.70
	4065	Stock	21.80
	1626	Labor	120.68
General Expense.........	$213.25	Cost	$603.43

operation; *i.e.*, all turning upon piece marked 6 *A* 2 are entered under "Turning" on the labor sheet, Fig. 92; so, also, with each of the other classifications, each line on the sheet showing not only the cost of a certain piece, but *the cost per operation.*

This, then, is the "hour-wage" method of determining cost; and while it falls short of the ideal system for which so many have labored, its free adoption would go a long way toward the salvation of those manufacturers who, though at present favored with their full share of orders, are destined sooner or later to be dropped from the list of the successful through their lack of a proper appreciation of the cost of production.

Fig. 92.

Average Cost per Operation of Labor per Pieces for One Machine.

on

Shop Order No. 1788.

Symbol.	Pieces.	Turning.			Planing.			Shaping.			Drilling.			Boring.			Chucking.		
		Ticket.	Hrs.	Amount.	Ticket.	Hrs.	Amount.	Ticket.	Hrs.	Amount.	Ticket.	Hrs.	Amount.	Ticket.	Hrs.	Amount.	Ticket.	Hrs.	Amount.
6 A 1	6		3	30															
6 A 2	6		2¼	45															
6 A 3	6		4	64															

Symbol.

Cutting Off.			Grind. and Pol.			Milling.			Scraping.			Assembling.			Painting.			Total.	
Ticket.	Hrs.	Amt.	Ticket.	Hrs.	Amount.	Ticket.	Hrs.	Amount.	Ticket.	Hrs.	Amount.	Ticket.	Hrs.	Amount.	Ticket.	Hrs.	Amount.	Hours.	Amount.

FIG. 93.

DISTRIBUTION OF PLANT CHARGES FOR MONTH OF AUGUST.

Hourly Burden, .22. 1.06 Per Cent. Ratio.

New Assets.	A	Standard Drawings	40	
	B	Standard Patterns	32	
	C	Standard Machinery and Tools	54	
	D	Special Tools, Jigs and Fixtures	30	
	E	Line Shafting and Accessories	15	
	F	Office and Shop Fixtures	5	
	G	Belting	20	
	H	Miscellaneous	4	
		Total	200	
Selling Expense.	I	Advertising	100	
	J	Office Supplies	25	
	K.....	Travelling Expenses	80	
	L.....	Drayage, Freight, and Expressage	180	
	M ...	Boxing and Crating	15	
	N.....	Interest and Discounts	50	
	O	Bad Debts and Extras		
		Total	450	
Manufacturing Expense.	P.....	Official Salaries	700	
	Q.....	Rent, Power, Taxes, and Insurance	250	
	R.....	Interest and Deterioration	600	
	S.....	Interest on New Assets	4	
	T. ...	Patents and Royalties		
	U.....	Light and Heat	31	
	V.....	Perishable Tools	175	
	W....	Shop Supplies	286	
	X.....	Drawing-Room Supplies	10	
	Y.....	Non-Productive Labor	430	
	Z.....	Miscellaneous	84	60
		Total	2,570	60
		Total General Expense	3,020	60
		Total Productive Labor = 13,730 hours	2,840	96

DISCUSSION.

Mr. Frederick A. Halsey.—I wish to take distinct issue with this paper on one point especially. In the table called Figure 88, office expenses and salaries are included as parts of the cost of production. My contention is that the items which are included in the cost of production include only those incurred inside the the shop door and not those outside. The expenses incurred outside the shop door are properly considered as cost of distribution and not of production. That is to say, while the expenses

incurred in the office represent part of the cost of goods delivered to the customer, they do not represent part of the cost of the goods delivered into the warehouse. This may seem at first like a distinction without a difference; but in point of fact the difference is more important than the distinction is plain, although, like everything else connected with the subject, the distinction is one whose importance depends on circumstances. In the case of a factory producing goods solely on order, where no stock is carried on hand, except what is actually in progress, the distinction would be of small importance, but in the case of a factory producing goods without regard to individual orders, but solely with regard to the state of the market, large stocks being carried, it becomes of very decided importance. The reason is this: When the annual inventory is taken for use in the balance sheet, an important item of the balance sheet, in the case of works which carry heavy stock of goods, is of course the value of those goods. I have known cases where the value of the goods on hand made the largest single asset of the entire business, and it became important to know what those goods cost and not to overvalue them. If they are overvalued it simply inflated the business; and that is the direct tendency of including these office and sales expenses in the cost of production. If that plan is followed it will simply value the goods that much higher, and make the value of the business appear that much more than it really is. In other words, it inventories the expenses and makes them show as an asset, a condition of things that cannot be defended. I know this is a common plan, but it is as wrong in principle as it is common, although, of course, where goods are made solely on order, it becomes of small importance practically.

There are generally two methods of determining how much money has been made at the end of the year. The cost of the goods can be determined by some such method as that of this paper, and from the cost and the selling price the profit on each sale can be found, the sum of its profits on all the sales of the year giving the annual profit. On the other hand, the annual balance sheet may be consulted, and between the results of the two methods there is usually a great gulf fixed, which of course is due to the inaccuracy of the cost-keeping systems. The reasons for this difference are diverse and obscure, but there are two sources of error which account for part of it, and which do not

receive the attention they deserve. One of these is the question of heavy tool cost. This question of the charges for the use of heavy tools is about the most difficult one connected with the subject, and it is one which this paper does not even mention as existing at all. In fact, the plan here proffered as "accurate," would place the same charge upon the labor of a boy running a fifty-dollar centring machine that it would on the labor of a man running a twenty-foot boring mill, the grotesqueness of which procedure will not be enlarged upon. It is a very easy matter to take the cost of the heavy tools, calculate a given percentage for interest, and wear and tear, divide the amount by the number of hours of labor in the year, and say that is the special charge to be made for an hour's labor on that tool. The trouble is that after that charge has been made it is not earned, because tools of that character are idle a large portion of the time, and during another large portion of the time they are used on work far within their capacity.

A small planer job will be put on a large planer because the small planers are all busy, but you cannot make a heavy tool charge to-day and a small tool charge to-morrow on the same job. The result at the end of the year is, that the total interest and depreciation of the large tools, based on average work, are written off, but, because of the above situation, it has not been earned. This, in my opinion, is one of the reasons why the methods of calculating profits which I have indicated do not agree.

I do not know of any way in which this difficulty can be met except by keeping of the tool time as well as the labor time. In that way the number of hours which a tool is in actual use can be determined. But saying it can be done in this way, it is a very different thing from saying that it should be so done, as it would involve a formidable addition to the system of keeping the books, and whether it is worth doing is altogether a question. It is a much easier matter to devise a system which will accomplish the desired results than it is to decide whether the results, when obtained, are worth their cost.

The second reason for the discrepancy between its result of the two methods of calculating profits relates to the disposition of non-chargeable labor. This paper treats this correctly, although not as neatly as it might. The common method here is to divide the workmen of the shop into producers and non-

producers, and in making up the ratio of loading to have the ratio on this division. In point of fact a good deal of the time of producers will actually get into non-productive work of various kinds, and thus vitiate the ratio as found above. My own plan is to do what this paper does—require every man in the shop to make out a time ticket at the end of the day, so that the tickets, as turned in, represent the total amount of labor done during the day. This is all done on a single ticket form, because the division is a matter for the office and not for the shop. At the end of the day these tickets are collected; everything that can be assigned to different jobs is so assigned, and the remainder is put into the scrap heap and charged against non-assignable labor, a running account being kept with this non-assignable labor, which, however, is not added up until the end of the month or year. When thus totalled, an accurate basis exists for calculating the ratio so far as it relates to the non-assignable labor, and any one doing this for the first time will be simply astonished at the result.

The error in both cases is greater than appears at first sight. In each case the error means a sum taken from the numerator and added to the denominator of the ratio, the error being thus a double one.

At the same time it is very easy to exaggerate the importance of these things. Every manufacturer makes his goods as cheaply as he can, or as he knows how, and sells them for all he can get, and the question of niceties in cost-keeping does not have much to do with either the income or the outgo of the business. While, therefore, these things are interesting and of importance, I do not think they are of such vast importance as a good many people think.

Mr. W. S. Rogers.—Taking this paper all the way through, I find it is practically about the same as I have in use, and many of the members say the same. I have been told by several that it treats of only the primary step in cost accounting. While that is true, we must bear in mind the fact that there are numberless factories where even this does not exist, and it will start them up the hill of progress. We must also bear in mind that there are shops, and shops, and shop-superintendents and superintendents, and all kinds of presidents, managers, and directors; different ways of doing things in different parts of the world, and different ideas among the powers that be as to

what constitutes an accurate cost account. I have tried several methods of cost-keeping, invented by others, and have had the misfortune to invent one or two methods myself (to my sorrow), and I have about concluded that there is no such thing as "an accurate cost method" that can be used indiscriminately. I fully agree with Mr. Halsey that the factory should be cut off and completely isolated from the business and sales department, with the superintendent's salary on the factory expense account. In this way the "cost of production" can be calculated continually in an almost straight line tending downward. And the business department can follow its own bent without hindrance, and add 10 per cent., or 100 per cent., to their "costs," as they deem best. In our factory, if materials cost \$40 and labor \$40, we have to add another \$40 to the total to arrive at the correct cost of the machine ready for the customer. This last \$40 is the 100 per cent., and is caused by clumsy methods of handling work and the high-priced directors holding positions, who put their money into the company and draw salaries for work they never do. But it is done the country over, and is one of the penalties which companies must suffer who do business above their capital.

If you and I are in business to-day, and want \$20,000 additional capital, we go to some wealthy man, and, after we show him gilt-edged profits, he is asked to make the investment, and puts in the \$20,000, with the understanding that we give his nephew—who has no business qualifications whatever, but has spent the greater part of his life attending social functions and prize-fights—a position worth \$2,000 per year. We do this, and then hire a clerk to do the work of our \$20,000 nephew at an extra expense of \$1,200 per year, and this sends the "fixed charges" up skyward. So, to be honest in estimating cost of production, I think every one will agree with Mr. Halsey that the dividing line begins at the superintendent's office, and the item of "factory fixed charges," with all its subdivisions, should be established.

In regard to "labor," I think Mr. Norris will divide and redivide this item many times as he gets into cost-accounting more extensively. It is very important to the progressive superintendent that he not only knows where all productive labor is employed, but also where the non-productive labor goes, that he may be able at any and all times to cut off all

useless expenditures and keep down his costs. I have found it very valuable to me to have the following items always before me:

Cleaning factory and equipment	$157 90
Experimental work	9 64
Factory supervision	3,316 76
Errands for general office	34 82
Foundry carrier work	742 14
Repairs, shafting, pulleys, belts	321 42
Repairs to machines and tools	452 98
Engine, boiler, and electric light	954 47
New jigs and fixtures	320 81

With proper methods of book-keeping it costs nothing extra to run these items, and their occasional study will save the annoyance of having the general office advise reduction of expenses, etc.

Here is a problem which is found in different figures, in different shops in various parts of the country, when the yearly inventory and accounting take place: The wages-paid sheet shows an outlay of $40,000; the production sheet shows a return of only $38,000; and the searching question is, Where is the deficiency? Why was it? After weeks of research and going over records, it is reduced to about $200, and every one has grown tired and disgusted, and the balance is crossed off to profit and loss. No one ever saw a $38,000 yearly wage sheet and a $40,000 yearly production. The nearest example I ever saw was in a foundry where the cost sheets showed a daily melt of eighteen tons of pig-iron and scrap overbalanced by a daily output of clean castings weighing twenty-one tons. The ideal cost-accounting system is one that shows daily where every penny's worth of wages has been expended, and can be balanced with the cost of production every night after the bell rings. Knowing that ideals are never realized, we balance our books once every week, and every item of time charged, with the right amount of fixed labor to it against the person or job to which it honestly belongs—should it be for sharpening the skates of the secretary's boy, repairing the harness of the president's family carriage, or sending a man out on family errands for other officials. If the method of time and cost-keeping is such that every item of work performed in the factory during the week can be located and charged correctly, so that the two

columns of wages and production will balance exactly, then we are getting very close to the ideal.

When an official of a company gets favors in the factory, he should be treated, not as one of the company, but placed on the same footing as Jones or Smith across the street, who are getting repair work in the factory. I do not believe in daily time cards "approved" by foremen and sent into the office. Foremen are for the purpose of getting materials to machines and men, and switching the work to avoid delays in machine operation, and not for performing clerical duties. My time and cost clerk takes the previous day's record of time and distributes it properly in about one hour, and sees personally about one hundred men. He also gets time during the day to visit about the factory in every department, and see what the workmen are doing; in fact, he is fully as cognizant of the detailed work of the men at all hours of the day as myself or the foreman. Consequently the distribution of cost of production cannot err much.

I do not think we will ever find an accurate cost system that will fit all conditions in all factories. We may take all the literature on cost-keeping in existence and find it will fit here and there about the earth, but not all points of the compass; and my method is to have no special hobby of my own, but boil it all out, and do as we were advised to do concerning the boiler-testing code—take what we want to accomplish our ends and throw the rest away.

Mr. Oberlin Smith.—I notice that in Fig. 88 of this interesting and thoughtful paper, in the list of expenses, two very important items are omitted which should enter as factors into the general account; one is *interest* on the total capital at a fair rate, and the other is *bad debts*, a very uncertain quantity. Whether the miscellaneous item mentioned is large enough to cover them I do not know. Be this as it may, does not the uncertainty just referred to render futile in some cases the unusual attention which is paid in recent years to minute details of cost-keeping? Analyzing these things month by month is all very nice, but it takes a good deal of bookkeeping, and often one's calculations are all "knocked out," so to speak, by some unexpected bad debt, or by some bad experimental work which happens some other month. My own experience has convinced me that it is better to work by the year, put a plenty high

enough expense rate, and be sure to get every expense item in. Some such, not mentioned here in detail, are telephoning, telegraphing, expressage, discounts for cash, etc.; but I suppose they have been included under general expenses.

It seems to me that the best way to get an expense account is to take *all* expenses, starting with interest on capital at five or six per cent., following with bad debts all commercial and mechanical expenses such as are mentioned here—insurance, taxes, depreciation, travelling, advertising, office expenses, repairs, power, heat, light, and the rest of it, including such amount of salary and wages account as is not directly productive. In some cases a part of the officers' salaries, especially in the engineering department, can be charged directly to certain jobs—in other cases not. Everything, however, should be charged to "expense" that is non-productive. All hours' time in the year, charged absolutely to producing articles to sell, is one item. All other hours, whether of officers, or janitors, or whomsoever, come into expense. If this total expense, liberally figured out, is divided by the total number of productive hours in the year, we have a system which, at the end of each year, gives from fifteen to thirty cents per hour as the expense rate—that is, for the average machine shop employing from fifty to five hundred people. For years I have been in the habit of using a twenty-five cent expense rate, and every hour, whether made by a five-cent-an-hour boy or a forty-cent-an-hour man, has that twenty-five cents added to it, which amply covers all expenses. Thus we have three items of cost—material, labor, and expense. The latter is based on the last year's experience, but in the course of years it does not vary a great deal. I have often found it twenty-one, twenty-two, twenty-three cents, etc., but have usually put it at twenty-five. As a shop gets bigger and more systematized it often can be safely put at twenty cents.

The foregoing remarks apply to the ordinary shop, which is usually semi-jobbing and semi-manufacturing, and which generally finds its cost of production and distribution somewhat mixed up. When we get down to pure manufacturing, as in making small staple articles of machinery, or cotton cloth, or patent medicines at a cost of three or four cents a bottle, which sells for a dollar, one can systematize far more thoroughly than can be done in the ordinary machine shop. If we could take

an average shop, employing a hundred or two men, doing some manufacturing and some work by the hour, and absolutely separate the commercial and the manufacturing elements, it would be easy to keep the absolute cost of manufacture alone. The machines could be merely made and set aside in a big room. We would find that a smaller expense rate would cover such making—probably about ten cents per hour. There would be no bad debts, advertising, travelling, or commercial work of any kind, except the trifles of buying material, time-keeping, paying off, etc.

I conclude, therefore, that (considering the *variable* commercial factors involved) it does not pay, as a usual thing, to incur the extra outlay for making up a new expense rate monthly. It does pay, however, to keep current-cost accounts of every job, monthly, or even weekly, using a rate which has proved, year by year, to be a safe average. There are doubtless many exceptions to this proposition—notably in cases of starting a new business, or in reorganizing an old one under new methods of management. In these, and other cases involving special conditions, I have no doubt that a strict monthly or quarterly analysis of cost, in the line of Mr. Norris's carefully worked-out methods, would often prove of great value.

Mr. L. S. Randolph.—This paper interests me greatly. I have had this matter to thresh over two or three times in my life, and in what I imagine is probably as difficult a position to get it right as any—that is, in the repair shop of a railroad. The question of uncharged labor bothered me at first. I felt that the charge should include everything in detail. My idea, I remember very distinctly, was to have the foreman distribute his time, but that was soon given up. The uncharged labor was obtained in this way: At the end of the month we took the total pay-roll, subtracted from that all labor which we could charge directly, and distributed the balance *pro rata* at a certain percentage, obtained by dividing the uncharged by the charged labor. I found that satisfactory. It made the labor accounts balance every month. We did the same thing with material. That is, the freight expenses and other charges were made *pro rata*. A certain amount of material is received during the month, the bills are kept until the end of the month, and all interest, freight charges, and labor in handling the material are charged *pro rata*, making a price at which each item is

charged out. The difficulty with repairs of tools and new tools was considerable; there we had to charge it per annum. At first the charge for these was made every month; but one month we got in quite a lot of new tools, and charged them all in at once, which made the uncharged expenses on material and labor amount to about 80 per cent. The management kicked on this, so that we had to change our bookkeeping and charge all such items upon a percentage basis, which was determined annually. This method of handling the uncharged expenses proved universally satisfactory, and satisfied me that the extremely accurate methods of cost-keeping amount to nothing, and are not worth their cost. The method of keeping the labor charged directly was by a ticket for each operation on each piece of job or shop order. Now, that looks a little cumbersome, but I found this: that I could separate those tickets and I could get the cost of the operation—for instance, if we were to take cross-heads on a certain order; there might be a dozen cross-heads, there might be one. We could pile all the tickets on that order in one lot, and separate them so as to get the cost of each operation, viz., drilling, chipping, planing, straightening, and fitting in the guides. There was the whole thing in detail. It gave me that, and also it gave a check on the men. I remember very distinctly the effect of a little increase in salary. I had a blacksmith making a peculiarly shaped bolt; they cost us $6.25 a hundred. I raised his wages about ten cents a day or twenty cents a day, and I watched him for two or three years afterwards, and he never got above three dollars and a half per hundred, and we saved on those bolts enough in a year to pay his increase of salary twice over. As regards the question of heavy tools, I have tried that once or twice, and never satisfactorily. The question of varying tool cost I have never been able to look upon as of much moment. I do not see its value unless you have very heavy and very light tools and extremely sharp competition. Of course, as Mr. Smith said, if we are making patent medicine, or something of that kind, making the same thing every day, then one can figure down to the last notch, but where you are doing this job one day and another job another day, it is extremely difficult to get anything more than an approximation, and I do not think it is worth trying for.

Mr. H. H. Suplee.—Mr. Randolph has brought up a point

which I think is of value, at least I know it was in one case, and that is the value of keeping the cost of the different branches of the work—the planing, chipping, turning, etc. This was in a case where machines were made in lots of six or eight or ten, and each lot was given its own order number, and its costs kept as a whole. These costs were carefully scrutinized in comparisons with the previous ones, to see if there was any difference, and if so, where that difference occurred. If the difference was in the planing or bench work it would be discovered and could be corrected. If the next lot cost less, the department in which the economy occurred could be found. So it was a very important piece of education in the shop, apart from being a mere cost account.

Mr. C. W. Hunt.—Before the discussion closes I would like to ask those interested in this subject of cost accounts to read a work entitled "The Commercial Organization of Factories," a voluminous and elaborate work by J. Slater Lewis, General Manager for P. R. Jackson & Co., Limited, Manchester, England. Blank forms necessary for the practical working of the system are given for all the operations.

This system is in use in our Staten Island factory, and we would be glad to show the general and detail working of the system to those who care to see it. There are no secrets, and I invite all to visit us who take an interest in the subject.

Our factory management and system of accounts are distinct from our commercial organization, with independent offices and separate bookkeepers, whose interests are opposite, as the goods are billed from the manufactory to the commercial office in a similar manner to the billing of goods from the commercial office to a customer. An increase in the factory bills means a decrease in the profits of the commercial organization, and a deduction from them means less shop profit; consequently, each bookkeeper is constantly on the alert to guard his own interests. This system is particularly valuable in manufacturing accounts, because it applies the double-entry system of bookkeeping, by which the correctness of the entries on the books and the blanks is checked by a monthly balance sheet, so that if an article is taken from the storehouse into the factory and incorrectly credited, or a mistake made in the figures, it will show in the trial balance at the end of the month, when the bookkeeper will institute a search and ascertain where the error

occurred. Once an entry has been made on the blanks, it cannot be lost sight of, and must be disposed of in the proper manner; otherwise the trial balance at the end of the month will not be correct. These trial balances of the various accounts are made still more valuable because the various expenses of the works, such as taxes, insurance, interest on the buildings, repairs, renewals, plant extension, office, and other charges and expenses, are reported monthly, so that it not only shows the accuracy of the entries by the clerical force, but also shows the results of the business for the month with a considerable degree of accuracy.

It will, no doubt, appear to many, as it did to us upon the first examination, that this system requires a very large clerical force, but we found that this was not the case, as proper blanks are furnished for all the operations, so that clerks on a small salary are employed to make the proper entries. When the works are not large one man fills two or more offices. The head bookkeeper must be a capable and efficient man.

Our works make a great variety of articles, many of them intermittently, and is a class of manufacture in which it is usually considered very difficult to apply an accurate cost system. We may get two or three orders in succession for an article, and then six months may pass before receiving another order for the same article. The system is as easily applicable to a wide range of manufacture as it is to a smaller range of duplicate work.

It has been suggested by the previous speakers that it is impossible to secure accuracy by a system of shop accounts. Mr. Brashear, measuring optical work to millionths of an inch, might not call it accurate, but, commercially speaking, it is not only accurate in giving the cost of a complete machine, but also in the details of the construction. The necessity of at once obtaining the cost of both the whole article and its details is far greater than most engineers realize. Business in these days of competition is likely to be lost if the estimate of the cost is too high, and money lost or no adequate profit made when the estimated price is too low. Again, the general tendency of all shop costs is to increase and the system to degenerate, unless an accurate and efficient system is adopted and closely watched by the manager, both in details as well as the general result.

I will not here attempt to give an outline of this system, as

if should be studied from the printed work before mentioned, but I will add the general statement that the manufacturing and the commercial offices are entirely distinct. The goods are received by a "storekeeper," who receives them, and enters all the items in the proper columns of his blanks provided for this purpose. When articles pass out of his hands, he enters them to the proper works order, on a stores issues book, no matter how trivial or small the article may be. A piece of scrap iron delivered for shop use is charged in just the same manner and as carefully as is new material. The storekeeper does not have to think of the value of the article, or what it is to be used for; he only knows that he has the proper written order for it, and enters the delivery on his records in the proper column.

These withdrawal orders are always in writing, signed by authorized parties, with the exception of very unusual events, such as the bursting of a steam pipe, or an accident requiring prompt attention; but in these cases the storekeeper makes an entry on his books, and at night he goes to the foreman, under whose direction the material was used, and secures an official order for the same.

Mr. Rogers.—Mr. Hunt has, in my opinion, the ideal system of keeping account of stock and running a stockroom. Whenever factory managers realize that the stockroom and its keeper should bear the same relations to the men in the factory that the proprietor of a country store does to the villagers and farmers about him, their cost-accounting system becomes a simple thing, easy to handle, and down comes cost of production. We have been doing this same thing for the past two years, and the whole plant is treated as a manufacturing village doing business with the storeroom; and no one, from the president down to the youngest apprentice, can get credit there unless his request locates where the material is to go, and he may expect to have bills rendered accordingly.

This system of Mr. Norris will not fit the ordinary job repairing machine shop, and I do not think he wishes it to be understood so, but is intended for factory use. Mr. Smith has brought forward a point, which Mr. Norris mentions in the last five lines of his paper, concerning the firms who "will be dropped from the list of the successful." Mr. Smith is right. There are many who don't wish to know what it costs them to manufacture, and it is better that they should not; and some

way or another they don't exactly fail, either. I know of one manufacturer right here in New England who has been in business for the past thirty years and has never taken an inventory. One day I asked him, "What did that machine cost?" He replied, "I don't know." I asked, "Why don't you know?" He answered, "I don't want to know; I know what I sell it for; that is enough." "How do you know when you are making money?" I asked. He replied, "You are dumb; you are foolish; you never had a bank account." (Laughter.) "I will admit all that, but tell me your method that I may get one," I replied. Then he told me the secret of success: "I go to the bank at the end of the year and find I have $20,000. All right; the next year I find I have only $15,000. Isn't that a sure sign I am losing money? Then I make a kick, and the next year I have $25,000; and there is no occasion that year to kick. Why should I bother with your cost ideas?" So I agree with Mr. Smith that all these things are not needed—if we don't want them.

*Mr. Norris.**—In preparing this paper for presentation to the Society, it was my aim to eliminate all detail not directly pertinent to the leading features of the system, hoping that the discussion would centre upon the salient points only, and not upon the minor accessories which, of necessity, must be suited to the requirements of the particular establishment in which the system is put into practice. Judging from the criticisms, however, I have either carried my pruning too far, or else a number of the opposing members have read the paper with little care, much of the evidence adduced strengthening rather than weakening the defence.

Replying, first, to Mr. Rogers' remarks, I am not surprised at his conclusion that there is no such thing as an accurate cost method if the one or two systems which he has invented permitted of a deficiency of $2,000 between the production and wages-paid sheets—a condition of affairs impossible to occur in my system. Every cent of wages which is not chargeable to a specific order number is charged to some one of the various items on the distribution of plant-charges blank, where it is fully provided for by the hourly burden account. All work of this nature is fully described upon blue cards, as explained on

* Author's closure, under the Rules.

page 391 of my paper, which, I think, amply meets Mr. Rogers' objections, that: "It is very important to the progressive superintendent that he not only knows where all productive labor is employed, but also where the non-productive labor goes."

Mr. Randolph and Mr. Suplee spoke of the value of keeping the cost of work per operation. In this, as well as many other points mentioned, I think our systems are substantially the same, except that by my method non-productive labor is entered up each day in the same manner as productive labor, instead of waiting until the end of the month and determining it by subtracting all chargeable labor from the pay-roll, which, though it causes the labor accounts to balance, can hardly be considered an accurate method. It is the temptation of every workman to throw as much time on general expense as possible, to circumvent which I require my men to fill out one or the other of the time cards shown in Figs. 85 and 89, the exact mission, or whole use, of which I have apparently failed to make clear. After all the slips have been assorted in reference to the workman's numbers, and the total time made by each is entered in the pay-roll book, the blue and white cards are separated into different piles. The white ones are then assorted according to their shop numbers, and the total number of hours and wages charged to each is entered in the daily labor book, after which the slips are pigeon-holed according to these numbers until such time as the orders are completed, when they are assorted with reference to the operation, and the hours consumed and cost in wages of each are entered on the labor sheet, Fig. 92. The white cards thus tell us five things outside of their use in marking up the pay-roll: first, that the time should be charged to an order number; second, what that order number is; third, upon what piece of that order number the work was performed; fourth, the length of time spent upon that particular piece; and fifth, the nature of the work done, whether turning, planing, or scraping, etc. The blue cards, on the other hand, tell us, by their color, that the time should be charged to general expense, which item may be subdivided as many times as thought desirable—even to having one for sharpening the skates of the secretary's boy, if Mr. Rogers so desires—the number of subdivisions in no way affecting the final results of the system, which are based upon the general expense considered as a whole.

Comparing my method with that of Mr. Smith's, there seems to be but one real point of difference between us—*i.e.*, the determination of the *exact* hourly burden monthly instead of *an approximate one* yearly. To approach anything, at all, like accuracy, a careful account must be kept of material, labor, and general expense. The first two of these must, of necessity, be figured day by day—why not go one step further and figure the third? What is the difference between adding twenty-six figures twelve times a year, and twelve times twenty-six figures once a year? It adds nothing to the cost of the system, but much to its usefulness. Of what value would a barometer be to a sea captain if it only gave the average conditions of the atmosphere for a year? How could he prepare for a storm? Conditions are ever changing: one month a number of new machines are added to the shop equipment; another month the force of workmen is increased; at another time new systems are introduced; later a part of the works is destroyed by fire; dull times come, and the men are laid off. Then a new machine is built, and the question comes: What has it cost? Will it be safe to take the hourly burden at the old rate in determining the selling price? Or must we let "the other fellow" fix the price, and then wait until the end of the year to see how we stand?

There can be no doubt but that a yearly determination of the hourly burden answers every purpose in Mr. Smith's case, otherwise he would not continue to follow this practice; but in my work I find it very essential to determine the burden by the month, for the triple reason that I have no old records to follow, I need the datum at once, and want greater accuracy than is possible by Mr. Smith's method. It is, however, mainly a question as to which is the better plan—to look at the compass every month, to see if we are headed in the right direction, or to wait for twelve months until we arrive somewhere to learn by how far we have missed our destination?

Mr. Halsey assails the paper on another side, contending that the items included in the cost of production should comprise only those incurred within the shop door, all others being considered as cost of distribution. He says that "while the expenses incurred in the office represent part of the cost of goods delivered to the customer, they do not represent part of the goods delivered into the warehouse."

If one wishes to know the *actual* cost of an article, in order to compare its present cost with its former cost, nothing should be included in "the cost of production" except hours, wages, and material, but if we want to learn the *whole* cost of anything for the purpose of fixing the selling price, or preparing an inventory, the "cost of production" should include a part of the president's salary, as well as that of the superintendent or foreman. All three come under the head of general expense, and I fail to see why office expense, *as I use it*, is not just as much a part of the cost of goods delivered into the warehouse as to the customer. If the hourly burden is taken at a fixed rate, as practised by Mr. Smith, there is no question but that an inventory, based upon these figures, would show an inflated value, and be the means of fixing the "great gulf" between it and the annual balance sheet alluded to by Mr. Halsey. But in my method there can be no gulf. If the books show that the general expense for a certain month is $5,000—$5,000—no more, no less—is distributed amongst all the orders worked on during that month, and it matters not, so far as cost goes, whether the product is sold immediately or lies in the storehouse for a year.

The question of tool cost was not mentioned in this paper for the reason that I consider it foreign to the subject. I have thrashed the matter over more than once to my satisfaction, and feel convinced that there is nothing in it except for such shops as use both very heavy and very light machinery. The difficulties connected with acquiring any degree of accuracy by the use of this method are stupendous, and the results, when obtained, afford but poor compensation for the additional cost of the bookkeeping.

Except for an infinitesimal amount of red lead and a little waste, a scraper-hand contributes nothing to the general expense account. A floor-hand, however, punishes, or entirely consumes, a large number of small tools and supplies. So, if it comes to a question of hair-splitting, I fail to see where Mr. Halsey would call a halt. The ideal system should give three things, cheaply, quickly, and accurately—the *actual cost* of any one piece, the *total cost* of any one piece, and the *total cost* of *all pieces*—whether wanted by the day, week, month, or year. So far as the total cost of any one piece is concerned, we know that only substantially accurate results are possible by any

method of cost-keeping, as there is always sure to be a more or less unfair distribution of the general expense item. Upon this point my system may be no better than a number of others, but I believe that it entirely fulfils the first and last of these conditions—hence the name: "An Accurate Cost-keeping System."

DCCLXVIII.*

A WATER-PURIFYING PLANT.

BY HOWARD STILLMAN, SACRAMENTO, CAL.
(Member of the Society.)

ABOUT a year ago the Southern Pacific Railroad Company established at Port Los Angeles, Cal., a plant or adjunct to the pumping station for the purpose of purifying the water supply at that point of the large amount of scaling matter it contained.

The chemical principles involved are based on the well-known Clark or Porter-Clark process.

The mechanical appliance or adjunct to the pumping station was the author's design, and the purpose of this paper is to describe the method as well as the "standardizing" of the process, since the plant referred to was established with a view to rendering the same applicable to other stations on the company's lines where the waters require purifying.

At certain places in England and elsewhere large and expensive plants have been put up for the purpose of purifying water for boiler purposes on a large scale. The method which we are to discuss is intended to do away with an elaborate system of works and to furnish a continuous supply of purified water of constant quality without the use of agitators to assist chemical action or the necessity for labor other than that in usual attendance at a water station.

It was also desired to do away with expert attention at remote points and avoid the danger of overdosing the supply, or going to the other extreme, with chemical solutions.

The treatment of water in the cold on a large scale was considered the cheapest and best method of dealing with it. No two waters from a natural source are just alike, and the treatment by boiler purges, compounds and nostrums, frequently exploited, is properly of value only in special cases.

On a railroad where steam boilers take water successively

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from various sources of differing quality the "cure-all" becomes a factor of doubtful value or even safety. The old saying that what is one man's meat is another's poison is equally applicable to steam boiler waters.

The consideration of each water by itself, and its reduction to lowest terms practicable with respect to the scaling and corrosive matter contained, seemed the best course to pursue.

The water at Port Los Angeles required a double treatment on account of the bicarbonate of lime contained, together with a large amount of the sulphates of lime and magnesia. The chemical principles involved in the treatment are not new, and it is not the purpose of this paper to discuss them at length, though reference will be made to them later, as well as the special character of the water treated.

The following is a description of the appliance:

The general plan (Fig. 94) shows a section elevation, and Fig. 98 a plan of the purifying addition and pumping station. As the system is independent of the action of the pump, except as a constant source of supply, that machine does not necessarily form part of our description. Referring to Fig. 98, the water main *a, a* is intercepted in its passage from the pump to supply tanks (Fig. 95) by the circulating tanks, Nos. 1 and 2. Detail of construction of these tanks is shown in Fig. 96. They are alike, each about 4½ feet in diameter by 8 feet high, and the space inside is divided up by partial diaphragms, alternately placed, allowing the water in its course to circulate upward, under and over, and check its motion, allowing time for chemical action to take place within them.

Their size is such as to allow the water about five minutes in passing through, and the tanks serve virtually as an enlargement of the water main at that point: the arrangement of the diaphragm or baffle plates is not essential to the process, and the circulating tanks are not intended to deposit or dispose of sediment. The water main enters tank No. 1 at the bottom and discharges at the top, thence to bottom of No. 2, again discharging at top, and on to the supply and settling tank (Fig. 95).

Just before entering each of these circulating tanks the water main is tapped by a ½-inch pipe, conveying in a steady stream, when in operation, a solution of desired chemical reagent from the chemical tanks at *b, c*. These chemical tanks are shown in detail at Fig. 97, and the ½-inch feed-pipes leading from them,

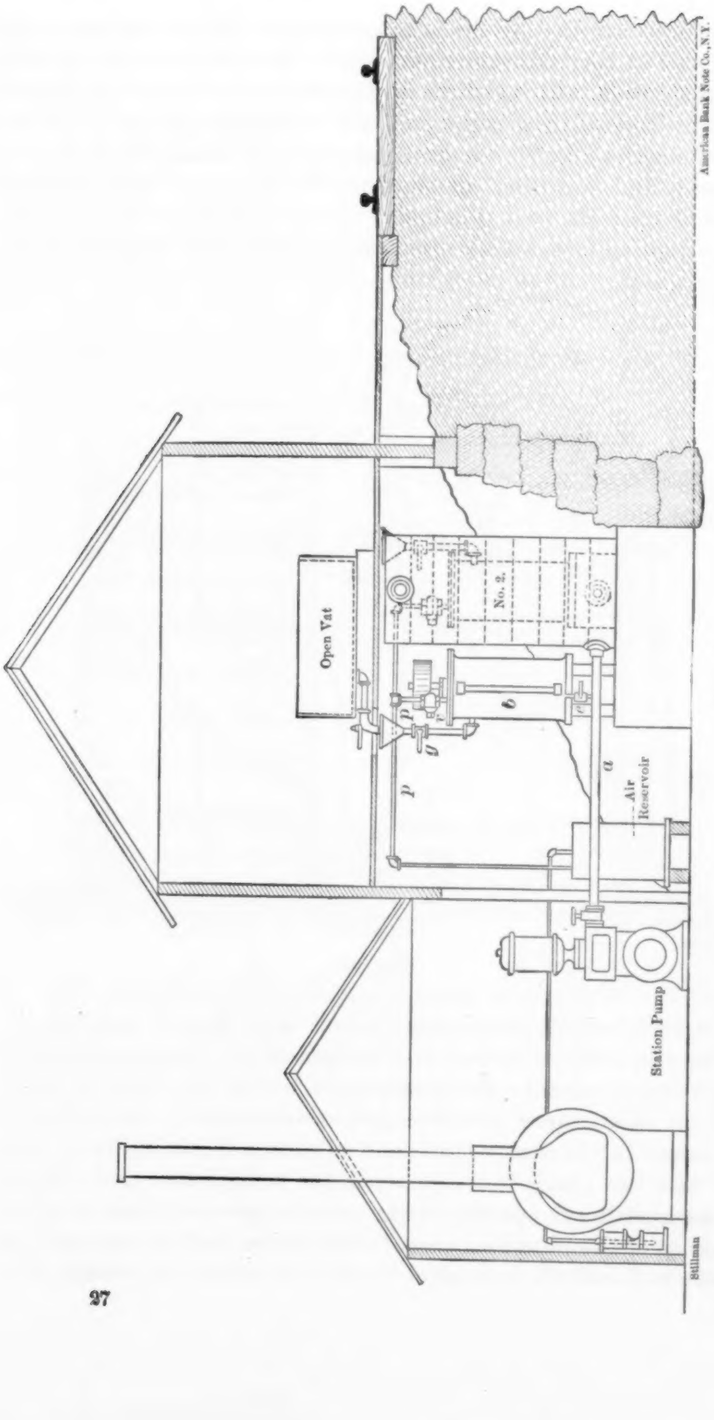

Open Vat
No. 2.
b
p
g
p
a
Air Reservoir
Station Pump
American Bank Note Co., N.Y.
Stillman

FIG. 94.

e, e, are controlled by the plug cocks *f, f*. These smaller tanks are also of like dimension, and hold 100 gallons when charged with solution, which suffices for four hours' continuous operation of the pump, or a supply of about 44,000 gallons of water. As shown in Fig. 97, the tanks are air-tight when all cocks are closed, and are filled through the $1\frac{1}{4}$-inch pipe and screened funnel when the cock *g* is open. The top is tapped by a $\frac{1}{4}$-inch pipe leading from an air reservoir supplied with compressed air

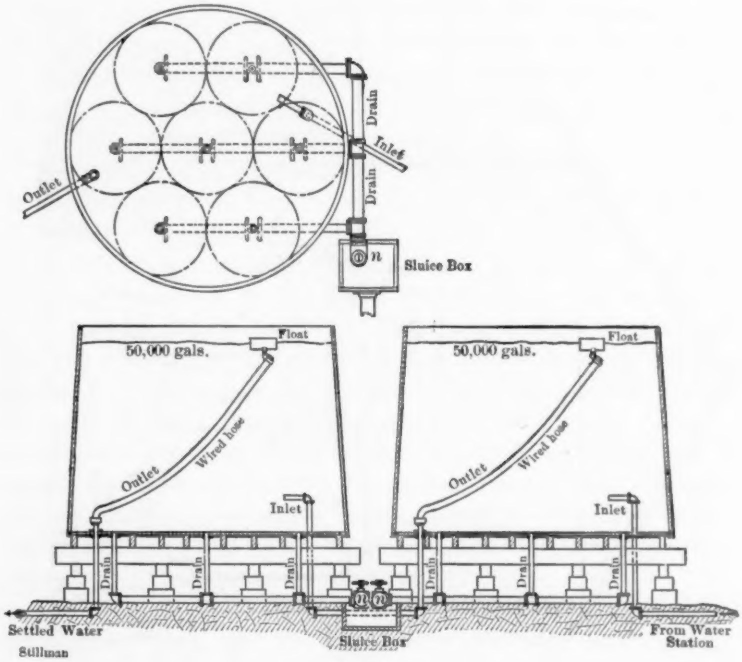


FIG. 95.

from an 8-inch Westinghouse pump. Just before entering the tanks the small air-pipe *p* is intercepted by a pressure-regulating valve *v*, whereby the air pressure within the chemical tanks is kept at a desired pressure, just overbalancing the hydraulic pressure in the water main, and allowing the solution to flow through the $\frac{1}{2}$-inch feed-pipe when the cocks *f* are open. These cocks are always operated wide open to prevent possible clogging up of the pipe by a casual obstruction, and the air pressure is allowed entirely to control the flow of solution to mingle with

the water flowing through the circulating tanks to the reservoir. The pressure-regulating valves are controlled in the usual manner by wrench and screw at bottom, so that the operator can occasionally adjust the feed of solution. Each chemical tank is about four feet high, and provided with a long-sight feed-glass so that the contents can always be noted. They are gauged to feed out eleven inches per hour, and when pressures are adjusted do not ordinarily vary. Occasional attention to the pressure valve during pumping hours, such as an engineer gives

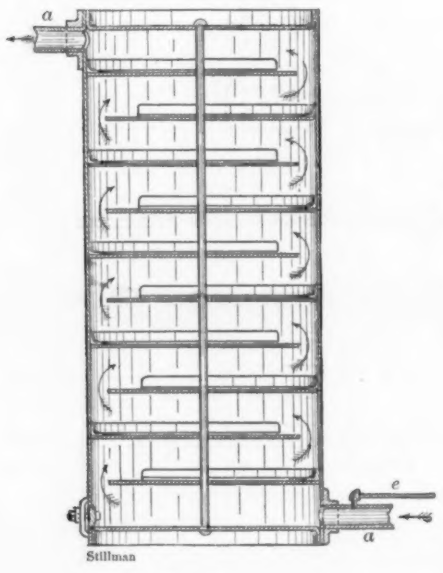


FIG. 96.

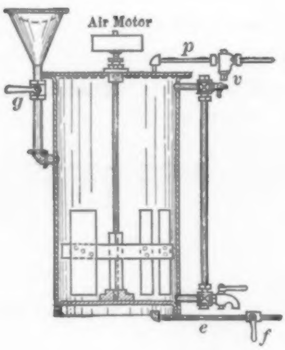
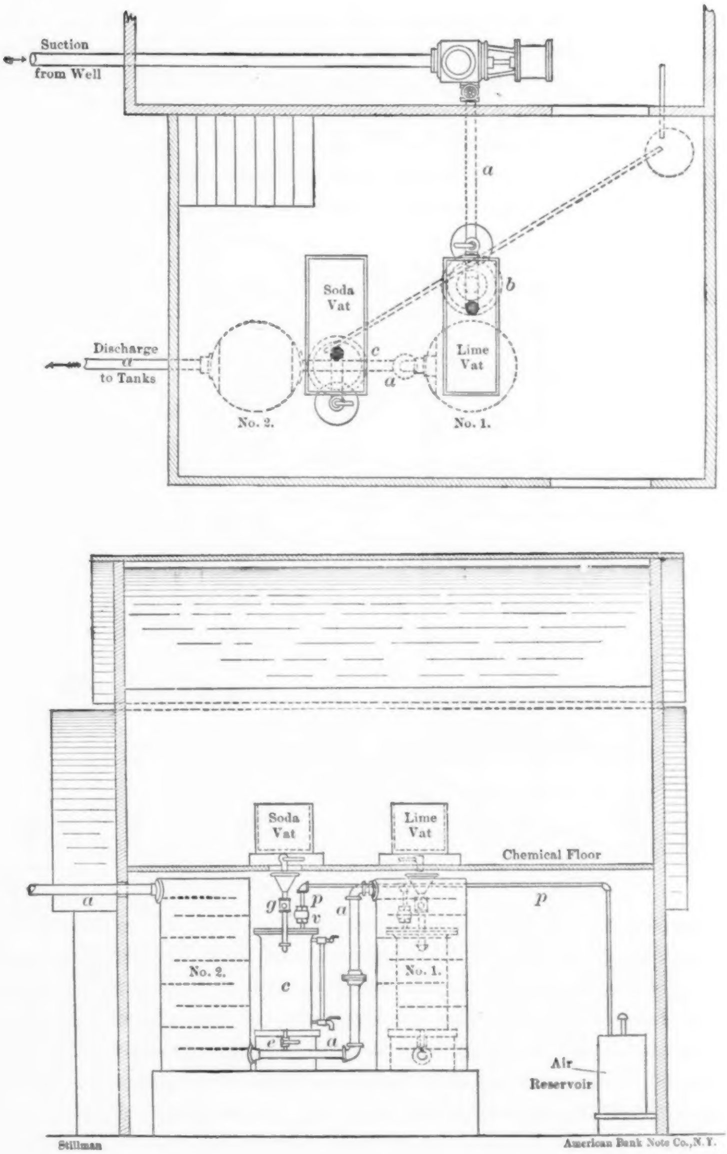


FIG. 97.

his sight-feed lubricators to steam engine or pump, is sufficient, inasmuch as the hydraulic pressure during pumping hours does not vary more than the head varies in a gravity supply. It has been found that the air pressure on the chemical tanks is about an atmosphere less than hydraulic pressure in the main, so that, as would be expected, the pneumatic action is to hold back the solution from flowing out too fast. As referred to above, this feed could have been regulated from the cock *e*, or the pipe made smaller, but it was desired that at no time should the operation "hang fire" by clogging of a small opening

FIG. 98.


Suction
from Well
a
b
Soda
Vat
Discharge
a
to Tanks
c
a
Lime
Vat
No. 2.
No. 1.
Soda
Vat
Lime
Vat
Chemical Floor
a
g
p
v
a
p
No. 2.
c
No. 1.
e
a
Air
Reservoir
Stillman
American Bank Note Co., N.Y.

When the pumping ceases, the cocks *e* in feed-pipes are immediately closed, and when again pumping is renewed the cocks are opened. At Port Los Angeles the hydraulic pressure is about 92 pounds gauge, and the discharge of the pump a little over 11,000 gallons an hour.

The chemical tanks are filled as required from the mixing vats, on the floor directly overhead, which is on a level with the track, as shown in Fig 94. These vats are open, and have $1\frac{1}{4}$-inch pipe connection at bottom, terminating in plug cocks opening downward through holes in the floor directly into the screened chemical tank funnels, for convenience in filling. The vats are rectangular in form and of such size that a 12-inch depth of liquid fills a chemical tank for four hours' continous run of pump. The weight of chemical material per 12-inch depth of liquid in the open vat gives a standard solution, and is based on the quality of the water and its hourly rate of flow through the main to the reservoir, which data give the key to the situation; as, for instance, supposing analysis and tests of the water show that it will require $1\frac{64}{100}$ pounds of unslacked lime to absorb the carbonic acid in 1,000 gallons. The flow through the main being 11,000 gallons per hour and the charge to last 4 hours, then we have $4 \times 11 \times 1\frac{64}{100}$, or 72 pounds of lime to be slacked with water to a depth of 12 inches (100 gallons) in the mixing vat. When slacked and mixed the liquid is a cream of lime, which is run off into the chemical tank when desired, as before stated.

The old English method of treatment required the lime water, or lime in solution only, to mingle with the supply being treated, and large tanks with agitators were provided for the purpose. It has been proven that such elaborate means are not necessary, and that in condensed form as cream of lime the chemical action is just as effective by the method described, the agitation being accomplished in the passage of the water supply through the circulating tanks or an equivalent arrangement to effect the purpose.

It requires about five minutes' time to refill the chemical tanks and recharge with air, at which time the water supply, or pump, is stopped.

The tank charged with cream of lime is provided with an upright revolving shaft carrying paddles, as shown in Fig. 97, and works through a stuffing box in the top by means of a small air

motor. The paddles revolve slowly when the tank is feeding into the main, and their purpose serves to stir up the milk of lime to prevent it settling out, and thus deliver a constant amount of lime to the water being treated.

We have just considered the operation of introducing quicklime into the water in proper proportion to effect absorption of carbonic acid and consequent precipitation of carbonates in solution. The roily water now passes on through circulating tank No. 1, and this part of the desired reaction occurs more or less completely. As referred to before, the water supply at Port Los Angeles contains, besides the carbonates in solution, a large amount of sulphates, lime, and magnesia.

These salts, not being converted by quicklime, require a second reaction. The use of the necessary amount of caustic soda to effect this would have been expensive, besides other objections to its use. Soda ash was good and cheap, but would react with the lime, directly, to form carbonate of lime if introduced with it; hence its use necessitated the second chemical tank, with its mixing vat, which is operated by the same method and simultaneously with the lime tank.

In this connection it may be stated that if the cream of lime and carbonate of soda were injected into the supply main from the same chemical tank, or in mixture, a series of chemical reactions would be set up which would theoretically terminate in the desired result; but, as stated, there would be a large amount of chalk formed directly, and there are other reasons why it seemed best to keep the reagents separate and make of it a double continuous process.

The soda tank is like Fig. 97, except that it requires no stirring device, as the solution is some distance from saturation and does not settle out. The weight of soda ash put into the soda mixing vat is dependent on same data as before: the amount required to convert the sulphates being $2\frac{2}{10}$ pounds (per 1,000 gallons), we have $4 \times 11 \times 2\frac{2}{10}$, or 96 pounds to be dissolved in water to 12 inches depth in the mixing vat.

The lime is prepared by placing the stated weight of a good commercial article (fresh burned preferred) in the vat and letting in from an adjacent hydrant enough water to slack, after which more water is added to the required 12-inch depth.

The soda is prepared in its vat in the same manner, except that it is simply a matter of solution which is quite strong yet

not saturated, hence no separation or crystallization of sal soda occurs in the chemical tank.

As the water in the main receives its second injection from the soda tank, it passes on through the circulating tank No. 2, where the carbonate soda effects its reaction more or less completely, and thence on to the storage and settling tanks, which are at least large enough to contain 24 hours' supply. The treated water is milky with precipitated carbonates, and discharges through the inlet pipe about 4 feet from the tank bottom. The outlet to this tank is a piece of 4-inch wired hose, the open end of which attaches to a float on the surface, as shown in Fig. 95. By this means the clearest water in this tank passes on to the second similar tank by the same method. Clear water is always obtained from the surface outlet of the second tank.

The chalk deposit is considerable at the bottom of the settling tanks and has to be drawn off occasionally, which is effected by the "spider-drain" system shown in Fig. 95, which consists in tapping the tank bottom with seven 4-inch drain pipes. The location of these drains is shown in the plan of one of the tanks (Fig. 95), the drainage areas being indicated by the tangent dotted circles.

The vertical 4-inch drain pipes open into larger horizontal pipes, and these into a 9-inch pipe at right angles, terminating in the sludge valve shown at *n*, Fig. 95. This valve discharges downward into the sluice box, and when opened the tank bottom is drained from seven equidistant openings, which keeps the chalk deposit down near the tank bottom and prevents the "angle of slope" which the deposit would assume with but a single central discharge, whereby the deposit would accumulate up along the sides of the tank to interfere with clear settling, and would also require an occasional scraping or shovelling out. Each of the tanks is provided, independently, with this spider-drain arrangement, though both sludge valves discharge into the same sluice box.

Experiments were made in the laboratory by the author on the time practically required to complete the chemical reactions. During the first hour after treatment it was noted that the sediment or chalk kept forming in addition to that deposited, showing that chemical action, as far as observation would show, was not complete, though at the end of two hours no more precipi-

tation occurred even in decanted water if left standing some days.

While for practical purposes it has been determined that sufficient tankage for a day's supply is ample to insure settled water, the system can be used by putting up a number of smaller tanks with less total capacity than a day's supply, provided the surface water from each tank drains to the lower part of the next, and so on, the final supply coming from the tank farthest from the water station. This, however, is a matter of circumstance and expense dependent on local conditions.

The following analyses are shown of the Port Los Angeles water supply in tabulated form "before" and "after" treatment. The analysis "before" is one of several which were made at intervals during a year previous to putting in the treating system. None of these analyses varied materially with the season. The analysis "after" was made about two months after the system went into operation, and is also one of several made during the past year, without showing material variation in the treated supply.

SOURCE OF SUPPLY, WELL IN BED OF SANTA MONICA CAÑON, ABOUT 100 YARDS FROM PACIFIC OCEAN BEACH.

	BEFORE.	AFTER.
Date of Analysis.	March, 1896.	December, 1896.
Treatment per 1,000 Gallons.		Lime, $1\frac{84}{100}$ pounds. Soda Ash, $2\frac{3}{10}$ pounds.
Contained in the water in solution in grains per U. S. gallon :		
Carbonate lime	14.29	.69
Sulphate lime	5.07	.29
Carbonate magnesia	1.22	7.15
Sulphate magnesia	17.15	1.63
Silica	1.34	.11
Alumina	.17	.17
Sulphate soda	3.56	27.92
Chloride soda	8.75	5.71
Total	51.55	43.67
Incrustating matter	39.24	10.04
Non-incrustating matter	12.31	33.63

Cost per 1,000 gallons to treat, 4 cents.

The above analyses are presented as showing in a commercial way the result of the treatment. The treated sample was taken from the supply pipe at the end of the company's wharf, about

a mile and a quarter from the settling tanks, which are placed on top of a bluff across the cañon and about 160 feet above the track.

The photograph (Fig. 99) shows the pump house and chemical floor addition thereto, at the right. The view is looking north toward the company's mammoth wharf, which partially shows, making out into the ocean to the left. The settling tanks are on top of the bluff and behind the trees growing there.

Returning to a discussion of the "treated" analysis, there is shown to be 7.15 grains per gallon, carbonate of magnesia, remaining in solution. Its presence seems due to the fact that the well water contained more carbonic acid than allowed for as in combination with carbonate of lime; hence the carbonate soda in its reaction with the sulphate magnesia produced, in part, the soluble bicarbonate of magnesia. It was found subsequently that an increase in amount of quicklime from $1\frac{64}{100}$ to 2 pounds per 1,000 gallons reduced the carbonate magnesia to about 3 grains per gallon, without an excess of lime showing in the treated water.

The analysis shows almost 28 grains of the neutral sulphate soda. This alkali is not desirable, as having a tendency to produce foaming if allowed to become too concentrated in the boiler, but is neutral in other ways as affecting water for boiler use. Its presence is unavoidable, as being the direct product of soda ash and magnesia sulphate ($Na_2CO_3 + MgSO_4 = MgCO_3 + Na_2SO_4$). The greater portion of the $MgCO_3$ is precipitated, but the soluble Na_2SO_4 necessarily remains, and, like other alkali salts, can only be removed from a water by evaporation.

While the treated water is not shown to be "purified" in the proper sense of the term, yet it is converted to a fairly good water for boiler use. Previous to treatment the water formed a large amount of very hard scale, with considerable corrosion. I have seen pieces of this scale $1\frac{1}{2}$ inches thick and weighing over a pound, which could be best pulverized on an anvil. Analysis of this scale showed it to contain very much more of the hardening element (sulphate of lime) than was due to the amount of that element existing in the water before use; hence it seemed most probable that superheating of firebox plates to force heat through the intervening scale to make steam led to decomposition of the sulphate of magnesia, forming, with the

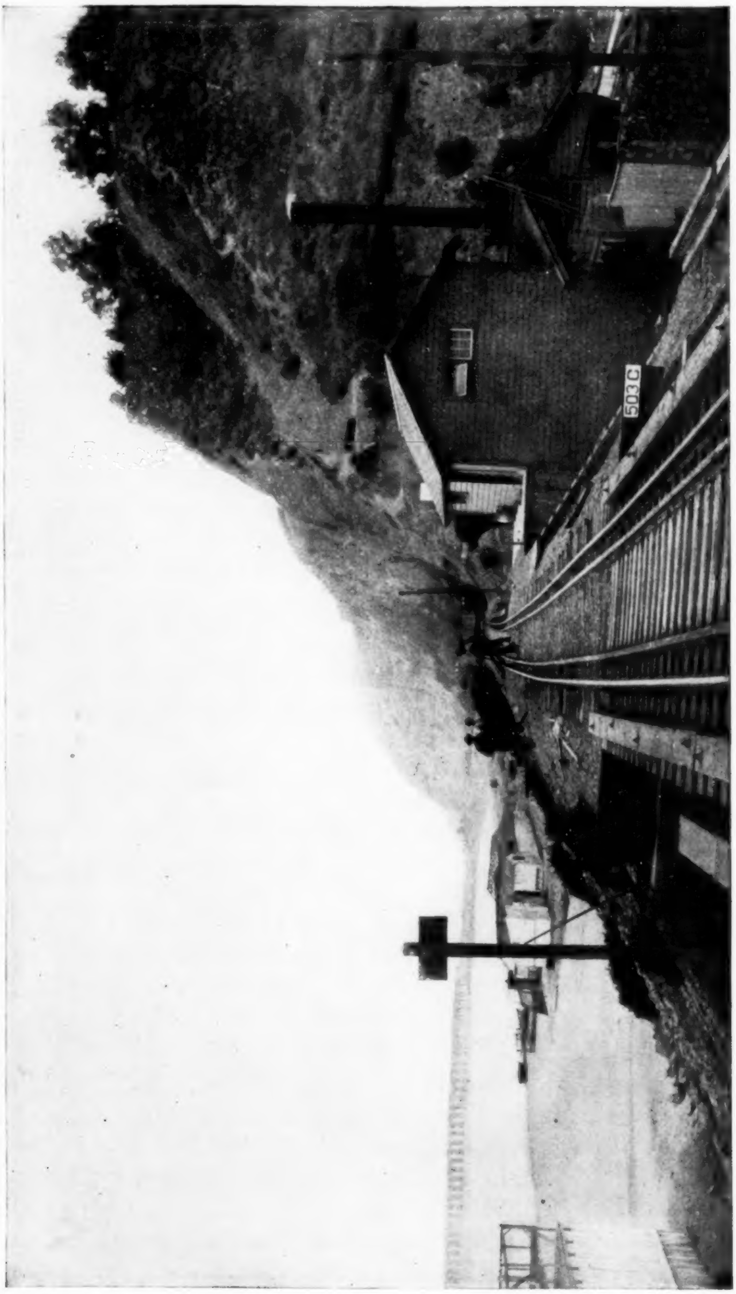


Fig. 99

carbonate of lime, more sulphate of lime and carbonate of magnesia. The superheating of the plates from the cause stated would possibly lead to decomposition of a film of water next to them and account for the corrosion, as oxidation under these circumstances would seem bound to occur ultimately.

It is not in place here to present chemical conundrums, and the author is not prepared to state whether the firebox and boiler flue corrosion was due to this cause or the carbonic acid in the well water. Before treatment the water badly corroded the supply pipes or water main leading to and from the supply tanks. I believe this corrosion was due to the carbonic acid in the water, as there are several instances which have come to notice at other points where corrosion in iron conduits of otherwise excellent water are producing disastrous results which can be traced to no other source as easy of explanation.

A switch engine with clean boiler was put to work on the wharf at Port Los Angeles, using only treated water, not long after the plant was put in operation, and observations made at intervals on the action of the water. No scale forms from its use, but a small deposit of magnesia sludge, having no tendency to form scale, has at times been observed. Otherwise the treatment has greatly improved the quality of the supply.

The author has done considerable experimenting in his laboratory, using different reagents and methods for the purpose of treating waters for steaming purposes. All samples were analyzed after treatment, and the double method described seems to have been much the more satisfactory in result.

As to the chemicals used for treatment, there are other reagents in the market for the purpose. Fluoride, phosphate, and hydrate of soda are among these and with which experiments were made, but the market price of these materials is not comparable with the dry carbonate, or soda ash, for the results produced. If, for instance, we wish to reduce the sulphate of lime in a well water (permanent hardness), it is practically immaterial whether the precipitate formed is fluoride or phosphate of lime, the neutral sulphate of soda (or potash) will remain as formed in the chemical exchange of bases. The phosphate acts somewhat quicker and the precipitate is heavier and settles sooner, but its cost is incomparable with soda ash (90 to 94 per cent. absolute Na_2CO_3) at less than two cents a pound.

As concerns the "temporary hardness" in natural waters

produced from bicarbonates of the scale forming bases, there seems to be no better or cheaper method of reduction than by use of quicklime. No reagent obtainable at the price will absorb carbonic acid more greedily. It is itself precipitated as carbonate of lime by the carbonic acid which it has taken up, and in thus depriving the naturally contained carbonates of their solvent allows them to precipitate also. Besides this, it will throw out of solution iron and silica to a certain extent as well as organic matter.

Some waters, from absence of incrustating sulphates, do not require the double treatment. For such stations the lime treatment alone is sufficient, and one tank, Fig. 97, with its adjacent circulating tank, Fig. 96, is made to serve.

The "standardizing" of the process for treatment of such waters as may thereby be benefited has been based on the following principles:

All tanks, vats, etc., to be made in sets of three sizes, the smallest being adapted to water stations having a delivery of 4,000 gallons per hour or less, the second 4,000 to 8,000 gallons, and the third 8,000 to 12,000 gallons.

Storage and settling capacity for a station to be sufficient for at least 24 hours' supply, unless circumstances allow other arrangement as to settling.

The character (from analysis) and rate of flow of water at a station being known, it remains to substitute such weight of reagents in a circular of direction, properly posted at the water station, as will supply necessary instruction to a person of ordinary intelligence.

DISCUSSION.

Mr. Albert A. Cary.—The purification of water for boiler use is a most important subject, which, I regret to say, has been sadly neglected by American engineers, and, in consequence, we find steam boilers all through this country suffering from pitting, corrosion, and scaling, which results in more or less rapid deterioration and increase in fuel bills, to say nothing of the worry and trouble connected with the attending repairs made necessary, and the laborious work required to keep the boiler in running condition.

This state of affairs is, in a majority of cases, unnecessary, as there are very few of the troublesome boiler waters which

cannot be treated in a comparatively simple manner by either mechanical or chemical means so that the boiler will be supplied with, practically, a pure water, and where water has been troublesome in boilers, such purifying equipments will be found to be one of the best paying investments in the entire steam plant.

Undoubtedly, the best method of treating boiler waters is to rob them of their scaling or corroding matters before allowing them to enter the boiler, but in some plants the equipment necessary for this purpose is regarded as too costly, and then there remains simply "the next best thing to do." Following this, and without proper advice, we find the boiler user often the victim of the many boiler quacks with both mechanical and chemical cures for all boiler troubles, who "treat" the water after it is fed into the boiler. All that the honest treatment of water *inside* of the boiler consists of is simply the use of some substance which will keep soft such scale as tends to form a hard, resisting crust, until it can be blown out, or removed by some continuous process, or else the use of some apparatus which will draw out continuously, or intermittently, the scale-forming matter before it has time to form a hard crust. These results can be obtained in the usual *partially* perfect way by the use of the cheapest chemicals or apparatus.

Many of the co-called boiler compounds are composed of these very cheap chemicals, but they are sold at prices ranging from five to twenty-five times their actual value, and as many of them contain positively harmful ingredients, I would advise boiler users to adopt them only after consultation with an experienced chemist or expert.

By describing this method of internal treatment of boiler feed waters I do not wish to be understood as endorsing the method, although I have been forced to adopt it in certain cases. I believe that a boiler has all it can do to furnish the steam required without converting it into a chemical laboratory, as ill results are pretty sure to follow such misusage sooner or later.

External mechanical treatment of boiler waters depends principally upon the fact that when water contains certain substances in solution, and when the temperature of such water is raised above a certain degree, more or less definite, this dissolved matter cannot remain longer in solution and, therefore, it is precipitated and held in mechanical suspension. This

precipitate, in one treatment, is deposited into the top, or onto the bottom or sides of catch-pans, where it is supposed to remain, the clear water passing onward into the boiler.

Filters are also used to remove all kinds of mechanically suspended matter, whether existing originally in the water or else being precipitated by some process from a chemical solution.

In the paper before us we find an external treatment by chemical means, which is very effective when properly designed and manipulated.

Mr. Stillman speaks of basing his process upon the Clark or Porter-Clark process. One might infer from what he has said that both of these processes are identical, but this is not so. The Clark process was originally a simple lime process; the lime-water (not cream of lime) is mixed with the water for treatment by the simplest means, and the precipitated carbonates were allowed to settle slowly in large and expensive tanks. The sulphates of lime and magnesia present in the water were not eliminated by this process. Mr. Porter followed Mr. Clark's invention with an arrangement by which he mixed the lime-water with the water for treatment, by use of revolving paddles, and then, without waiting for the precipitate to settle, he forced his water, with its mechanical solution, through a filter press, from which was delivered practically clear water.

In the method described by Mr. Stillman he treats his water in two separate processes, first mixing his cream of lime in the water for treatment, to throw down the carbonate of lime and carbonate of magnesia, and afterwards he mixes the carbonate of soda (or soda ash) with this partially treated water to throw down the sulphates as carbonates.

To those who are not familiar with these chemical reactions in the treatment of boiler feed waters, who care to follow this subject, I would refer them to a popular article which I wrote, and which appeared in the March, April, May, and June numbers of 1897 in the *Engineering Magazine*.

I have been quite successful in treating similar water to that described by Mr. Stillman, by a single-process method, using, instead of the cream of lime, lime-water, which I have found very much more satisfactory, and instead of using the carbonate of soda, I have used caustic soda, which acts quicker than the carbonate of soda, and seems more powerful in its effect. Probably (when acting upon the sulphate of lime) it more readily

decomposes the sulphate of lime, forming sulphate of soda (which is soluble) and liberating hydrate of lime, which readily absorbs the available carbonic acid, thus resulting in a most desirable reaction.

My lime-water is made in one of a pair of tanks, while the completed solution is being drawn from the second similar tank of this pair. The solution of caustic soda is drawn from one of another pair of tanks. To introduce these two solutions in a fixed proportion to a given volume of water to be treated, I use a large pump to feed the water to be treated to two large settling tanks, and attached to the piston rods of this large pump are two small pumps, similar to those used for feeding oil to screw machines. The length of the stroke of these small pumps is made variable so that they will each deliver a definite proportion of the two solutions with the water for treatment, and thus I obtain a fixed and positive chemical mixture in exactly the right proportion.

The two large settling tanks are similar to those described by Mr. Stillman, with the exception of having a stirring device which insures a positive mixture of the solutions with the water. After taking the treated water from the settling tanks, I pass it through a filter or filter press, and thus rob the water of all of its mechanically suspended matter, putting the purest possible water into the boiler, containing never more than the equivalent of three grains of carbonate of lime per U. S. gallon.

In Mr. Stillman's apparatus we find that after the "cream of lime" and solution of soda are mixed in the tanks on the upper floor, these are fed by gravity into the "supply tanks" below, and then air is compressed over the surface of the liquid in these "supply tanks," which causes these solutions to flow on and enter the "circulating tanks," with the water for treatment. This method of feeding solution may do for plants where a constant quantity of water is pumped almost continuously, but I am afraid that for variable loads, such as occur in mills and electric lighting and power stations, there would be a great deal of trouble in securing exact proportionate mixtures of the solution and the water for treatment by feeding in this way. In the circulating tank described by Mr. Stillman, I do not see how it is possible for a perfect mixture of the water for treatment and the solution to take place. The analysis given by Mr. Stillman, on page 424, showing the condition of the water after treatment,

would indicate this to be the fact. I believe that with a good stirring apparatus placed in the circulating tanks, and with the removal of the shelves or baffles shown, very much better results could be obtained.

I am interested to know how Mr. Stillman cleans out all of these tanks. A precipitation certainly must take place in them, and I cannot see how they can be properly and easily cleaned. In the first process, where the "cream of lime" is used, many of the little particles of suspended lime must become inoperative by receiving a coating of carbonate of lime, when they come in contact with the carbonic acid in the water, and it seems to me that the "cream of lime" would deposit some of its suspended matter upon the shelves of the circulating tank, where its surface would soon be changed to the carbonate of lime, and the balance beneath then becomes inoperative. When the "cream of lime" is used for this purpose, a very considerable percentage must be wasted, and therefore a large excess of lime is necessary.

From the last "circulating tank" Mr. Stillman passes the water on to the large settling tanks, and his method of connecting them in series, although not new, is excellent.

I referred a copy of this paper to the We-Fu-Go Company, of Cincinnati, who treat waters in a very similar manner, and in reply to my letter they state: ". . . It seems to us that the only advantage in using a continuous process is that it can be made more or less automatic in its action, and in this way reduces the amount of attention or labor necessary to keep it in operation, and, furthermore, that a properly designed apparatus of this kind would furnish a greater quantity of purified water, with a given sized plant, than by the intermittent method of purification.

"It seems to us that Mr. Stillman has failed to accomplish these points. We doubt if his apparatus can be run with as little attention, and I also doubt whether his apparatus would not cost more for a given capacity than is claimed. Furthermore, I think it extremely doubtful whether he can get perfectly clear water from his plant, although he states that he can. . . . In regard to feeding, I think that your method is superior to his, but of course you would not be able to handle a cream of lime in place of lime-water. It is pretty hard to state, without having had sufficient practical experience, whether a cream of lime could be used successfully, but I know

that it is contrary to all other experimenters in this line. . . . There is no question but what stirring the water with a paddle is better than mixing it as he does; in fact, I doubt whether it could be mixed successfully in that way. . . . There is no good reason why he should not be able to add all his reagents at one time, so far as we can see it, although he may have other reasons, which he does not state in this paper, for doing this; but the experience of others has not shown that any benefit is derived by separate treatment.

"Kindly ask Mr. Stillman if he ever had any trouble, or still has trouble, with the injectors which feed this water into the boilers, or with the check valves. We would be inclined to think that with the water handled in this way there would be some trouble due to a deposit which would form."

In conclusion, I would say that if this discussion has raised a question of doubt in the minds of any of the gentlemen present as to the ability of this form of apparatus to perform its work satisfactorily, easily, and economically, I will say that such doubt may be dismissed at once, as this process is a very efficient and desirable one, and it is one very largely used in England, France, Germany, Austria, and Belgium, while here in America we are just rubbing our eyes and waking up to appreciate the very material saving which it affords in prolonging the life of the boiler, in saving fuel, and in reducing our bills for cleaning boilers.

Mr. L. S. Randolph.—I notice the paper says something in regard to the objection to making a chemical laboratory of a boiler. I have had this problem to handle on one or two occasions, and I had that same objection at first. I have used soda ash, soda—that is, carbonate of soda—and quite a number of different chemical compounds, and I failed to detect the first signs of corrosion or failure of the boiler. In the last year or two, in fact about three years ago, I had a problem of this kind referred to me. We had a 60 horse-power return tubular boiler which was chock full of lime, and I do not suppose we got more than 40 horse-power, and had to drive pretty hard to get that. I was asked if there was not some cure for it, and my reply was that there was no excuse for scaling. We used a carbonate of soda, and the scale commenced to come off rapidly, in fact so rapidly that we could scarcely keep the boiler cleaned out. It also had the effect of making the flues leak. The flues had scaled around

and become hard and brittle and crystalline, and they had also drawn away from the flue sheet, allowing the water to get there; then the scale would form between the flue and the sheet and choke it up. As soon as the soda struck this place it would take the scale out and the boiler would leak here, but this leakage caused external corrosion to such an extent that we had to throw the boiler away and get another. Since that time we have been using a compound, which is said to be a secret compound. I do not think it is anything more than carbonate of soda, but it kept the boiler perfectly clean. We blow out pretty regularly, and clean out probably once in two or three weeks. We have two 30-horse-power boilers in which we have been using soda ash and commercial carbonate, sometimes one, sometimes the other. We put two to three pounds of soda in every two weeks, the water having about one-quarter to one-third of the scale-forming impurities which the author mentions. These boilers are clean, and give us no trouble whatever. There is scarcely no scale on at all. I examined both of them very carefully and have yet to find any sign of corrosion. Several years ago Mr. Gibbs, of the Chicago, Milwaukee, and St. Paul Railroad, published an article in the *Railroad Gazette* which goes into this thing very thoroughly, and I am satisfied from my own observation, and what I remember of his article, that the cost of using chemicals in the boiler is very much less than one would have from this method on a basis of four cents per thousand gallons. I am not prepared to say, though, that that method of putting chemicals in the boiler would answer where you have as much scale-forming matter as this water has. I know it has worked very satisfactorily up to a range of twenty-five grains per gallon of total solids. This article of Mr. Gibbs stated that he used there soda ash and soda. In my own neighborhood at Roanoke I found that the Roanoke Machine Works, where they had a thousand or so horse-power using very bad water, most of it lime carbonate and sulphate, they had no difficulty. When asked how they managed it, the reply was: "Our firemen put in a little soda every now and then." In regard to the action of carbonic acid gas on iron: I have had at one time and another considerable experience in that line, and am rather in doubt as to its having any effect. We find no corrosion whatever where we have been running two or three years, and frequently I have found that cases of corrosion were unques-

tionably due to the expansion of the boiler or the steam pipes causing the oxide of iron which formed to crack off, allowing the water to come in contact with fresh iron. In a paper read, I think, at the Chattanooga meeting of this Society, I called attention to the effect of these strains in causing corrosion. My attention was first called to it on an old anthracite engine on the Erie Railroad, where we had long flues from one end of the firebox to the other, and between them short thimbles going from the inside of the firebox to the outside. Now, under these thimbles, where the two sheets were held rigidly together, there was no corrosion, but under the long flues there was considerable corrosion; the only explanation we could get was that the contraction and expansion of those long flues bent the sheet and caused corrosion immediately under it.

Mr. E. N. Trump.—From an experience in the purification of feed-water for boilers of about 12,000 horse-power, in the last ten years, we have found that soda ash is the best ingredient for the purpose. We used caustic soda when we first started in, but it seemed entirely unnecessary to use a more costly material. The purification of water depends entirely on the composition of the impurities, and no one should attempt to purify any specific water without knowing its analysis. The use of soda ash will take out only the sulphate of lime. The carbonate of lime can be removed either by quicklime or by heating the water to a temperature of about 60 degrees centigrade. We use probably 2,500 tons of water per day, and we purify it by mixing it with a measured amount of liquor containing a known proportion of soda, which is put into it in tanks, the water having been previously heated by the use of exhaust steam, or we use waste waters which are already hot. The correct quantity of the solution is ascertained by the water being tested carefully by the use of chemical reagents. It is necessary to have quite a large tank, and a considerable amount of time, to allow the reaction to properly take place. The precipitation of the carbonate of lime, produced by the reaction between the sodium carbonate and the sulphate of lime, goes on quite slowly, and it is necessary to allow a little time. We remove that precipitate by the use of sand filters, which seem to give rather more economical results than an ordinary filter press. In Europe a great many of the German works purify water in this same way by the use of a settling tank. The

apparatus is in a simple plant of a single tank with a central pipe, in which the water is pumped, the reagent being allowed to drop into it continuously. The settling is produced by a series of inclined plates, through which the water rises very slowly, and the sediment precipitates into the lower part of the tank (which has a conical bottom) and is drawn off. We have used the *continuous system* quite successfully by using a sand filter in connection with the boiler, allowing a solution from a small tank, in which the soda ash is put and dissolved in water, to drip slowly into the suction of the pump. It is necessary, however, in that case to circulate water from the blow-off of the boiler through the same filter, in order to obtain a temperature of 60 degrees centigrade. We have two pumps, one for pumping water into the boiler, and a small pump for circulating from the blow-off of the boiler into the same filter. In a small boiler plant, where we have only about 600 horse-power, we obtain a perfect purification of the water by the use of soda ash only. We use no lime, because as long as the water is hot enough precipitation takes place without any difficulty. The carbonic acid is driven off by the heat, the bicarbonate of lime decomposed, and the carbonate of lime immediately precipitated. The purified water contains sulphate of soda, and a quantity of the water in the boiler must be blown off at intervals or the water will foam. As the simplest method of determining the amount of sulphate of soda, we use the Beaume hydrometer, and when the test is above three degrees we find we must blow off or we get foaming. The boilers have stayed very clean indeed. When we started this process we had as much as half an inch of scale in three months, and in some cases the boiler tubes were almost entirely closed up. It became necessary to do something, and about ten or twelve years ago we designed a plant for the purpose of removing the impurities from the water before feeding it into the boiler, which is the most satisfactory manner of dealing with it. Before that time there were various compounds presented to us for use in our boilers, all of which were analyzed (as in the course of our business we analyze all the substances we deal with), and we found a majority of these compounds had from 75 to 90 per cent. of soda ash, and it seemed, therefore, that the soda ash was the only ingredient which it was necessary to use, and undoubtedly it is the best for the purpose and the cheapest.

There are a great many substances which are now sold at very high prices, which are of no value whatever for the purification, because they are often used in waters which have no impurities which they will precipitate.

A Member.—I would like to ask the member where his boilers were located, and what style of boilers he referred to.

Mr. E. N. Trump.—Babcock & Wilcox boilers, which we are using in Syracuse.

The following analyses of water, before and after purification, are submitted as an example of the process.

All quantities in grams per 1,000.

	Water Before Purification.	Water After Purification.
CaS^{o}_{4} (Calcium Sulphate)	.205	.0405
CaC^{l}_{2} (Calcium Chloride)	.080	....
$CaHC^{o}_{3}$ (Calcium Carbonate)	.090	....
MgC^{l}_{2} (Magnesium)	.060	.050
$MgHC^{o}_{3}$ (Magnesium Carbonate)	.004	....
NaC^{l} (Salt)	.074	.164
$Na_{2}S^{o}_{4}$ (Sodium Sulphate)	....	.1007
$Na_{2}C^{o}_{3}$ (Sodium Carbonate)	....	.299

The purification of this water was accomplished by adding to the impure water about five pounds of soda ash per 1,000 gallons. Only about three-fifths of this is theoretically required to do the purification, and the balance appears as excess, but we have found this excess necessary to produce proper precipitation of the impurities.

Mr. Samuel M. Green.—In a battery of Manning boilers of about 600 horse-power, at the mills of the Merrick Thread Company, Holyoke, Mass., we have had a great deal of trouble from scale forming upon the tubes, and then dropping down upon the crown sheet. Many kinds of scale resolvent have been tried, including soda ash, kerosene and crude oil, but it has been found almost impossible to keep the tubes from leaking. About three years ago an electro-purifier was brought to my attention. It consists of a series of copper and zinc plates placed in an upright pipe. The feed-water is passed up through this pipe, and comes in contact with the zinc and copper plates. It was found necessary to keep the temperature at above 170 degrees. When putting in this purifier I did so with a great deal of misgiving, but it has since proved itself reliable. I do not think that its action upon the scale-forming properties in

the water has been explained, but the fact remains that our boilers have been free from scale since its installation. The scale, instead of forming hard upon the boiler surfaces, is deposited in the shape of mud, which is blown out every day. The zinc plates in the purifiers are renewed once a year, at a cost of about ten cents per horse-power.

I have put this purifier upon several plants, in one case particularly where the water was from an artesian well. In this plant as soon as the purifier ceases to act the boiler immediately becomes coated with scale. As long as the zinc plates are active the boiler is kept clean.

Mr. Randolph.—Would the speaker be willing to mention the maker's name of the heater and purifier of which he speaks?

Mr. Green.—This purifier is made in Hartford by the Curtis-Hull Manufacturing Company. It was, I think, originally a Chicago invention.

The zinc and copper plates are in the shape of rings, with fingers projecting towards the centre. The copper plate is simply a thin sheet metal, the zinc plate being a ring about three inches long. The two purifiers we have are about ten inches internal diameter and are each about five feet long.

Prof. R. H. Thurston.—What becomes of the solid matter precipitated?

Mr. Green.—The mud which is precipitated in the boilers is blown off every day, and the boilers are washed thoroughly once in two weeks. There is almost no hard scale except that which collects upon the tubes—a very fine, feathery deposit.

Mr. Wm. Kent.—I saw that electric purifier at the Electrical Exhibition in New York, two years ago, and, after hearing what the gentleman had to say who was advertising and selling it, I came to the conclusion that it was a humbug, and I have not yet found any reason to change that conclusion. There is a principle laid down by Herbert Spencer that every cause produces more than one effect, and every effect comes from more than one cause. That is a very important thing to remember in engineering. When one puts this electrical purifier on to a boiler, some other thing took place at the same time which did the work of diminishing the scale, and the so-called electric purifier itself didn't do it. It was a change in the blowing off, or in the water, or something else.

Mr. Geo. I. Rockwood.—I do not fully understand Mr. Kent.

He is full of paradoxes at this meeting. He says there are humbugs which are successes, which is a brilliant paradox. But facts are stubborn things. Now, Mr. Kent, as I understand the purport of his remarks, takes the ground of the man who wanted his boat painted and said "I don't care what color you paint it, as long as you paint it red." Mr. Green is as hard a man to convince of the truth of extraordinary claims as any one of my acquaintance. What does he say his experience has been with these purifiers? He states that his boilers, which had been covered with scale, and given trouble by giving out at the tubes for years, were rendered clean, and kept so, by simply changing the plant in one respect; that is, by adding these purifiers. Not only is this Mr. Green's experience, but it is the experience of several others. I also know that this purifier has been unsuccessful in some cases. I see a friend here now who has one that is partially unsuccessful, if not totally so. I would also say that I met the entertaining salesman whom friend Kent described so fluently, and I may say I said as much to him myself. However, I think that we engineers do make a great mistake in presuming, as we often do, that we have the whole of the applicable theory of any given problem, and we do well to "go slow" in stating our positive opinions.

Prof. R. H. Thurston.—I am reminded of a device for such purification of boilers, an "anti-incrustator," brought out years ago. It was an "electric purifier," and we had marvellous reports of the results of its application in various directions—and quite as marvellous reports of the things it did not do in other cases. I always had the feeling, although without personal experience in the matter, that there was something in the thing, after all; there seemed to be unquestionable testimony of its efficiency in many isolated cases, notwithstanding the fact that it still more frequently failed. Years after that it became customary, in the management of marine boilers, to introduce slabs of zinc, and the French, the British, and our own navy have been accustomed, now for years, to prescribe the introduction of slabs of zinc into their boilers, set in metallic contact with the metal of the boiler itself. That makes a Voltaic system, and I do not suppose any man, to-day, who is at all familiar with that sort of practice, has much doubt but that the introduction of zinc has proved itself to be often very valuable; I

am not at all sure that it is not always successful where it is properly used.

Mr. Kent.—What is it used for—to prevent pitting, isn't it?

Professor Thurston.—No; it seems, for some reason, which I do not quite understand, to prevent the sulphate of lime coming down in the form of hard scale. It is still sulphate of lime, but it does not cover the heating surface with incrustation; it is not hard as marble or harder, as is often the ordinary scale, and it is easily washed out. This particular device, just referred to, is one with which I am not familiar; but it is evidently simply a device for the introduction of zinc, not into the boiler, but into the warm feed-water before entering the boiler. The presence of the copper may not be of the slightest importance, because if zinc is placed effectively in contact with the iron of the boiler we have a Voltaic circuit—perhaps not as effective, perhaps not giving as high difference of potential, as the electricians say, as with copper, but the effect would be the same in kind. I am inclined to think that this may not be a humbug, after all.

Mr. W. F. Durfee.—At the risk of being voted a humbug with a great deal of unanimity by our sceptical friend, I will state some experience of my own. In 1867 I had under my charge, among other boilers, a small locomotive boiler of ten or twelve horse-power. We were using the water of Lake Michigan in that boiler. There was a hard scale deposited which gave us a great deal of trouble, and some one—I do not recollect now who it was, and am not at all sure whether he had a patent on the idea or not—suggested that we get a small battery and put this boiler in the circuit. We got a battery, a single cell holding about a quart—an ordinary battery, zinc and copper element; nothing unusual about it—and connected the smoke box of the boiler with one wire, and the firebox with the other. (Laughter.) Now, that was an electrical system pure and simple. There was no question of zinc having anything to do with the water, and I can testify, at the risk that I assumed in getting up, that the scale, or the material of the scale after that connection, and while that battery was in use, instead of being deposited as a hard, adherent solid, difficult of removal, was precipitated as a mud which we could blow out and wash out.

Mr. Gustavus C. Henning.—I would like to say that chemists have very carefully explained the reason why an electric current,

in the presence of steam generation, will or will not permit the production of hard or soft scale; that is, hard scale or mud. In waters which contain certain elements, if an electric current of any kind is introduced, scale cannot form because crystallization cannot occur in the presence of this electric current. Now, the effect of this copper and zinc in a boiler, instead of the boiler itself forming the positive electrode as the copper would do, a better current is established than in case of the ordinary method of introducing zinc into boilers referred to by Dr. Thurston. If a strong current be established the boiler under certain circumstances will suffer and become leaky in the course of time. If a copper electrode, which is the positive one, be introduced, the zinc will all be eaten up and no danger will come to the boiler. This battery is simply more powerful. Now, it is a well-known fact that in many chemical transformations one result will be produced in cold water, another in warm water, and totally different results when the material itself is affected by an electric current, either surrounding or passing through it in the presence of heat; and that would appear to be the simple solution of the problem here. A battery as described, of zinc and copper, can prevent the formation of a crystalline structure in the presence of the right sort of an electric current passing through the liquid which contains the materials. Of course if the water does not contain the right materials or some others which counteract the effect of the current, scale will form, or there will not be any deterrent action, but in conditions like those which Mr. Green has to contend with, the electric current undoubtedly does the very thing: it prevents the formation of crystalline sulphate or carbonates, and allows them to remain in suspension in a shape in which they can be blown out; and I think that what Mr. Green said is entirely so—that he has a case in which his practice bears out the true theory, and of course those who do not know the true theory might say that the battery or device used is a humbug.

Mr. C. L. Newcomb.—Having tried one of the Curtis-Hall Manufacturing Company's Electric Automatic Feed-Water Purifiers, and being the gentleman at whom Mr. Rockwood seemed to be looking when he remarked, "That some men tried the purifier with success and some without," I feel that I should add my experience to what has already been said on the subject. At the suggestion of Mr. Green, I located one of these

so-called electric purifiers in the feed-pipe of my boiler plant, which consists of two 80-horse-power horizontal fire-tube boilers, carrying ninety pounds gauge pressure of steam. Feed-water is pumped through a coiled exhaust-steam feed-water heater, then through said purifier. The purifier receives the feed-water at about 200 degrees. The purifier was in use about six weeks, and the inside of the boilers was, during this time, beautifully whitewashed by the deposit which the purifier did not remove from the water. I then called in the manufacturer of the purifier for advice, and he explained the inactivity of the purifier by saying "It was on wrongside up," and, on his advice and assurance, I turned it over. (Laughter.) I could not see what difference turning it upside down was going to make, but being willing to give it all the chance possible, I turned it over and used it again for about six weeks or perhaps two months—long enough to burn out the tubes of a Lamprey water front over the firing doors. The inside of the boiler continuing to be beautifully whitewashed with deposit, I then cut the purifier out, and notified the manufacturer that I would do no more experimenting with the purifier, unless he would bear the expense, which he would not do. Therefore my use of the purifier stopped, and my direct experience ended.

The water used was taken from an artesian well, the hygienic analysis of which is as follows:

HYGIENIC ANALYSIS OF WELL WATER FOR DEANE STEAM PUMP COMPANY.

The water contains in 1,000,000 grains:

Common salt		6 grains.
Ammonia		0.2 grains.
Carbonates		11 grains.
Lime and magnesia		9 grains.
Nitrates	A trace only	grains.
Lead	None	grains.
Iron	Trace	grains.

Remarks.

Odor—none.
Aspect—perfect.

Conclusions.

The water contains:

Sewage—none.
Drainage water—none.
Surface water—none.
Hardness—1 degree.
Lead—none.
Purity (scale for alluvial soil)—98½ per cent.
General character—an excellent water; no impurity of any account.

It is interesting to notice that this analysis shows a good quantity of common salt, which should make the galvanic action strong and the purifier efficient, according to the manufacturer's statements.

I wish to say that Mr. Green has, to my knowledge, one of these electric purifiers on a plant that takes its water from a driven well, located only about 200 feet distant from the well from which I took the water for my experiments. The purifier on this plant seems to give fine results.

It may be well for me to say that it was not necessary for me to use the well water for my boiler, as I have a good supply of Connecticut River water, which is excellent for boiler purposes. The well water is used in the plant for drinking and other domestic purposes, and, knowing its detrimental qualities, it offered a good opportunity to make the experiment with the electric purifier.

Mr. H. H. Suplee.—In this connection I think probably Dr. Thurston will bear me out in recalling that one of the earliest attempts to use galvanic action, not quite in the same manner, but very nearly so, was that made by Davy to prevent the corrosion of the outside of the hulls of vessels. Davy made some experiments, and showed that where zinc was present a circuit was formed, and the corrosion would be transferred to the zinc. I believe at the Royal Institution, in London, sheets of copper with zinc attached are still shown.

Mr. John T. Hawkins.—It seems to me that in the discussion of this question a provision which nature itself has made for cleaning boilers is largely lost sight of, and that but for that provision there would be much more difficulty in keeping boilers clean where a deposit of the salts of lime is concerned, and I think that most engineers who will refer to their experience in this matter will bear me out. We all know that carbonate of lime is held in solution in water because of the presence of carbonic acid, which is also held in solution, and that the amount of carbonate of lime which can be taken up or dissolved is somewhere in proportion to the carbonic acid existing in the water, and the amount of carbonic acid held in the water will be somewhere proportional to the pressure to which the water is subjected. What I wanted to point out was this fact, with which, I think, engineers will generally agree: that such boilers as are periodically allowed to get cold and become relieved of

pressure will deposit the carbonate of lime in the form of a powder or mud in the bottom, which can then be blown off when steam is again raised, and that nature does provide for that very feasible and complete way of keeping boilers clear from lime scale. If it were not for this fact we would find these lime salts invariably deposited as a crystalline scale upon the boilers, such as we know occurs in boilers under long periods of steaming; and in no case where boilers are periodically allowed to cool down at comparatively short intervals, and thus allow the carbonic acid to escape from the water, a deposit of lime salt is made in crystalline form upon the heating surfaces.

The rationale of these processes is probably something as follows: With the lime salts in solution in the feed-water, a boiler may be steamed under a given pressure without deposit of crystalline scale for a period which is limited by the water in the boiler becoming saturated with carbonic acid for that pressure and temperature, and can dissolve no more of the lime salts; after which, if steaming is continued, it begins to be deposited as crystalline scale upon the surfaces. If, however, at or before the point of saturation is reached, the boiler be allowed to cool down and become relieved of pressure, the contained carbonic acid escapes in the gaseous form, and, the water being unable to hold lime salts in solution, the latter are precipitated and settle to the bottom in the form of mud, and may be ejected through the bottom blow-off.

I have wondered if some of the supposedly successful scale-preventing compounds or processes do not owe their apparent success to the fact that the boiler is run under such conditions that scale would not form without them, and whether the terms "electric," and other attractive names applied to them, are not parading in borrowed plumes.

Mr. S. M. Green.—Whether the apparatus which I am using is a "humbug" or not, the fact remains that it has worked very satisfactorily upon this plant. It seems hardly fair to criticise anything of this nature until one has had practical experience with it. Water from the Connecticut River is used in this plant, and it seems that it must be the same from year to year. When the zinc in the plate disintegrates we immediately find that scale begins to form in the boiler. As soon as new zinc plates are put in the scale disappears. I think, without any question, it is a very excellent piece of apparatus for use in our mills.

Whether or not it will work in all localities, I cannot say. If I can buy "humbugs" which will work as well as this one does, I am always ready to invest.

*Mr. Howard Stillman.**—The paper under discussion was written last fall after the plant had been in operation a year, which period of time seemed proper to afford a reliable description of its practical operation and effect on the extremely bad water in question. On looking over the discussion I had, at first thought, found a mare's nest, but upon further consideration I had reason to believe there were hornets in it as well.

At this point I would rise to explain that the object of the paper was purely to offer an example of practical operation of the water-treating plant for what information it might convey, and not to ride a hobby into a peaceful convention.

I would most heartily concur with Mr. Cary in his remarks as to the importance of the purification or treatment of boiler waters when such may be done and local conditions allow a profit in the operation. The older countries of the world have been doing it for some time, and the "American lethargy" will pass away as the principles of the matter are better understood.

Concerning the "Clark" or "Porter-Clark" reference, I admit partial error in this statement. The reason was that when the plant was put up we were not sure of getting clear water as an outcome, so we provided as part of the system two Porter-Clark filter presses of 2,000 gallons capacity, each, per hour for filtering the water after leaving the surface of the second settling tank. These filter presses proved, however, unnecessary, as there appeared no suspended matter for them to collect, and they have not been in use for a long time. For a period of over a year the filter cloths have not been renewed, and needed cleaning but once.

As not, therefore, forming a necessary adjunct to the plant, no reference was made to these filter presses in my paper, and I only allude to them now in proof of my statement as to clear water obtained from the surface of the second settling tank. I hope Mr. Cary will inform the "We Fu Go" organization (sounds like of Chinese origin, possibly a new "Tong") that such is the case, and, if they further doubt my statement, that the operation

* Author's closure, under the Rules.

is still in progress at Port Los Angeles, California, where they may see for themselves.

In regard to a variable feed from the chemical tanks, in a general way the criticism is a natural one, but local conditions are overlooked by Mr. Cary, as, of course, he would not know of them. The steady delivery of the Dow pump at this water station was considered, and the rate of feed as practised is, of course, adapted to it only. As working entirely under pressure of over six atmospheres it became necessary to resort to compressed air to allow the chemicals to flow from the feed-tanks as explained.

There is some deposit of chalk, etc., within the circulating tanks, though by far the greater part is carried on with the rush of water into the settling tanks. The plant had been in operation over a year before it became necessary to clean the circulating tanks out, which was done by removing wash plugs placed opposite alternate diaphragms. These wash plugs were overlooked in making the drawing (Fig. 98). Tanks are now washed out with a fire nozzle once in two months. When wash plugs are removed, the inside of the tanks fairly bristle with *soft* chalky formation adhering to stay bolts and sides, as well as to the top and bottom sides of the diaphragms.

Mr. Cary refers to the deposit of particles of lime by reason of a film of carbonate forming over them, rendering the portion underneath inoperative. There is no evidence of such deposit of uncarbonated lime within the circulating tanks. I was prepared for such event, in my first experiments, with cream of lime in bicarbonate water instead of the prevailing use of lime in solution only (lime-water), but demonstrated to my own satisfaction in the laboratory that such loss, if any, was very small, and did not figure in the cost of the process considering the greater cost of more elaborate means to be employed in making use of a solution of lime only. The undissolved particles of lime oxide seem to take up their quota of carbonic acid as readily as if in solution and practically, in any event, effect their purpose.

If, as intimated by Mr. Cary, "the use of 'cream of lime' instead of lime-water is contrary to all other experiments," the method is new, which I had anticipated, and was one reason for submitting my paper. The lime should be well slaked. We now use in the lime tank eight-tenths of a pound of dry lime per

gallon of water. To insure an easy-flowing mixture, the liquid should be not stronger than one pound per gallon of water.

There has never been any indication of corrosion from the use of soda ash, either about the plant or in boilers using the water, though care has been taken to avoid excess, not from danger of corrosion, but because locomotive boilers will not carry alkaline carbonate waters and do very hard work without priming.

As to the quality of the treated water, it has been stated in criticism of the principle of treating boiler waters that the case in instance is of doubtful utility, because the purified water still contains about *one-fourth* of the scale-forming solids. The nature of this matter as not forming scale in the boilers is referred to in the body of my paper, but the criticism is seemingly absurd when we consider the matter in light of other economic propositions, a fundamental axiom of which is "a half a loaf is better than no bread." In the case in point we have shown three quarters of the loaf, yet the process is quoted as of "doubtful utility." As a general proposition, it is safe to assume that any manager of affairs, engineering or domestic, is highly elated over any proposition which nets him fifty per cent. improvement over existing conditions, and that I would place as the least income in saving from use of the water-treating plant at Port Los Angeles.

It should be borne in mind, though reference has not before been made to the fact, that previous to placing the treating plant there, our people had prospected the entire region for better water, but without success. It became, therefore, what is known in the West as "a ground hog case," to do something with the water to improve its quality.

Referring to the analysis given of the treated water in my paper, the chief objection to it, as shown, is the seven or more grains of carbonate magnesia. As stated in the text, we afterward found that by the use of two pounds of lime per 1,000 gallons, this amount was reduced to about three grains per gallon.

The tendency for waters containing a large amount of magnesium sulphate to hold in solution carbonate magnesia to a certain extent (whether treated with "cream of lime," or lime-water, to reduce carbonates) is marked, as I have found in several cases when experimenting with other waters, and the complete precipitation of magnesia is difficult. The salts of calcium are much more easily reduced and eliminated.

From evidence in the discussion it seems to be the opinion of

some engineers that all that is necessary with the use of bad scaling water in boilers is to reduce the scale, or prevent its forming within them, without regard to the disposition of the sludge that is bound to form in place of the scale.

As stated by Mr. Randolph, there is no excuse for scale in boiler waters, though why it is not better to settle out this sludge in a suitable place, away from the boiler, is not to me apparent. Very little to be blown or washed out is much better than a good deal to be blown or washed out, whether sludge in a steam boiler or dirt on a shop floor.

We must admit that the matter, however, is largely one of circumstance and local conditions, whether a boiler compound (proportioned to suit the water) is (in stationary practice) of value or not. Sometimes they are undoubtedly of more economic value than an elaborate purifying plant. On locomotive boilers I do not think boiler compounds are ever preferable or cheaper than a purifying plant. Generally they are of no practical value in locomotive service for reasons referred to in the text of my paper.

There is a great field for profitable work in the purification of boiler waters, and further hope for the operation, when the "cure-all" man has found other fields to labor in, when the quality of a boiler water is considered and understood; again, when the matter has come to be fully considered in the light of a proposition which rests on business principles and involves economies as well as the other difficulties which are met with in our engineering profession.

DCCLXIX.*

THE STEVENS VALVE GEAR FOR MARINE ENGINES.

BY ANDREW FLETCHER, HOBOKEN, N. J.

(Member of the Society.)

It has been urged upon me that the *Transactions* of the American Society of Mechanical Engineers should contain some record of the origin and introduction of the form of valve gear for beam engines which has grown to be so general in the side-wheel practice of the marine engine-builders of the eastern section of the United States, and of which the firm with which I am connected has been for so many years an advocate.

I have thought that this could best be done by getting from Mr. Francis B. Stevens a communication to me in which this history should be included, and which I might illustrate by drawings from more recent practice. Accordingly, two letters are appended herewith, and the drawings are self-explanatory.

I may be permitted to add that Mr. Stevens is eighty-seven years of age, and is still an enthusiast upon steamers of all kinds. My own connection with his form of valve gear began forty-four years ago, with my first connection with the old firm of Fletcher, Harrison & Co. during twenty-seven years; W. & A. Fletcher for three years; and the W. & A. Fletcher Co. for the past fourteen years.

HOBOKEN, N. J., *April* 2, 1897.

MY DEAR MR. FLETCHER:

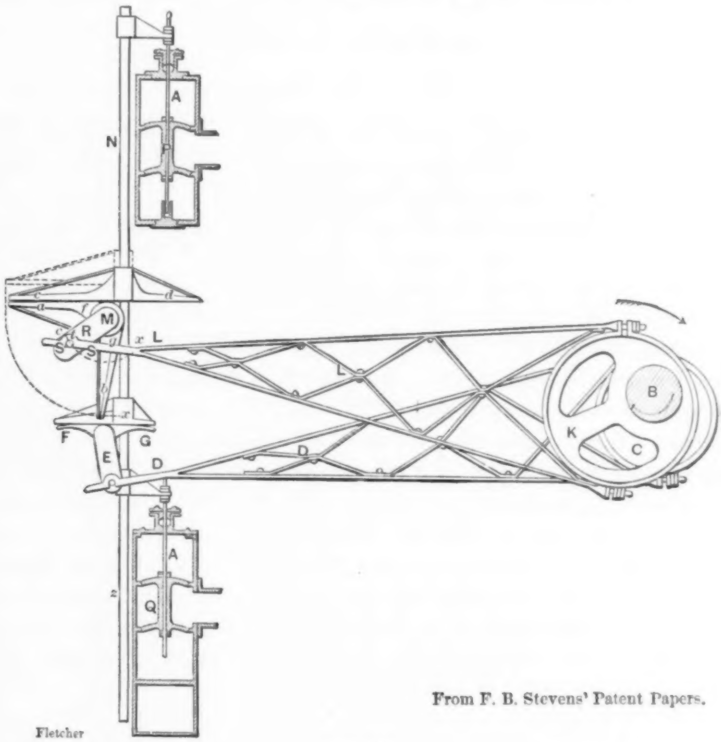
In answer to your request, I send this letter in relation to the Stevens cut-off.

Previous to its introduction in the year 1840, the form of valve and valve gear in almost universal use on the steamboats navigating the rivers and bays of the Atlantic coast was by poppet valves, operated by a single eccentric and a single rock shaft, the admission and exhaust of steam being coincident. Expansion was effected by a butterfly valve on the steam pipe worked by cams on the shaft,

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

which was called the camboard cut-off. On the *Mississippi*, at the date mentioned, the engines were the same as at present in use, having poppet valves worked by cams on the main shaft.

In the latter part of the year 1839 I invented the Stevens cut-off, and early in the year 1840 I had the machinery for its application on the engine of the steamboat *Albany* made. This vessel was owned by my father, and the machinery was made by H. R. Dunham & Co., North Moore Street, New York, where you served your apprenticeship. As the work was not finished until after the open-



From F. B. Stevens' Patent Papers.

Fletcher

FIG. 113.

ing of navigation on the Hudson, I was unable to attach it to the engine until the following August, when the *Albany* was laid up for repairs at Cold Spring, opposite West Point. And in the interval I had similar machinery of smaller size made by the firm mentioned, and put in operation on the engine of the steamboat *Columbus*, owned by my uncle, Robert L. Stevens. The engine of the *Albany* had a cylinder 65 inches in diameter and 9 feet stroke. That of the *Columbus* was 40 inches diameter by 12 feet stroke. The cut-off as first applied was essentially the same as at present. On the *Albany* the length of the toes was 26 inches and the lift of the valves was 5½ inches.

On submitting to my uncle, Robert L. Stevens, my model of the cut-off, made

on a scale of 1½ inches to the foot, he proposed an improvement, by substituting a cog wheel for the arm of the rock shaft, by which a greater angular motion of the rock shaft, and consequently a shorter cut-off, could be obtained. We then agreed to take out a patent in our joint names, with the understanding that I was to have complete ownership of the patent. And in April, 1840, I made the drawing that accompanied the patent, a copy of which, on a reduced scale, I annex. The patent was granted on the 25th of January following, the claims being as follows:

1. "The combination of an additional and separate eccentric wheel to work a

Fig. 101.

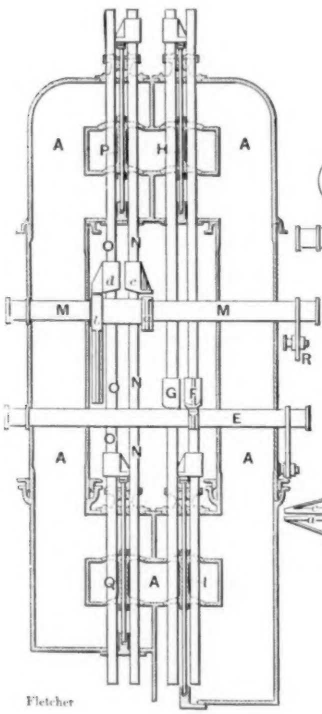


Fig. 102.

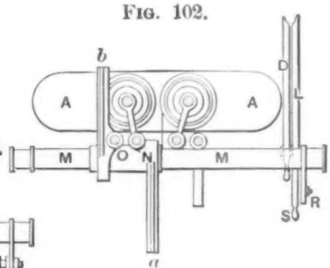
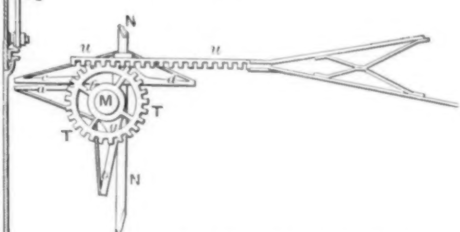


Fig. 103.



From F. B. Stevens' Patent Papers

rock shaft to raise the steam valves in combination with any of the several methods hitherto used for working the exhaust valves.

2. "The manner in which the toes are affixed to the rock shaft so that the shaft is made to vibrate during a certain interval, without either toe communicating motion to either valve.

3. "The connection of the cog wheel and rack, in the manner set forth, for the more completely effecting our object." This connection was never used, being found unnecessary.

The patent was renewed in 1855 and expired in 1862. Its validity was never attacked, and none of its claims was infringed during the twenty-one years of its

existence. Since it expired, separate eccentrics for the steam and exhaust valves have been frequently applied in combination with the Sickles, the Allen, and other cut-offs.

In the course of the year 1840 I applied the cut-off to the engines of eight steamboats, namely, the *Albany*, *Columbus*, *Rochester*, *De Witt Clinton*, *Independence*, *Swan*, and two steamboats on the Delaware; and shortly afterwards I sold a half-interest in the patent to my father, James A. Stevens.

In the year 1842 the Stevens cut-off was applied to the engine of the United States steamer *Fulton the Second*, and afterwards to the greater portion of the paddle-wheel vessels of war of the United States Navy.

In 1845 it was applied to the steam frigate *Mississippi*. The contract for it, made by my father and myself with the Navy Department, required that the cut-off should be made adjustable while the engines were in motion. To effect this, devices made at the works of H. R. Dunham & Co. were applied to quickly change the angle of the toes, the position of the arm pin, and the lead of the eccentrics. This vessel was the flagship of Commodore Perry's squadron on the famous expedition to Japan in 1853–54. And Mr. Daniel B. Martin, afterwards Engineer-in-Chief of the United States Navy, reported that this adjustable cut-off worked perfectly during the whole cruise, lasting about two years. The cut-off has been made adjustable on river steamers by this and other plans; but the advantage gained has not been considered equivalent to the increased complication of the machinery. Previous to and during the Civil War, the cut-off was on many large ocean steamers.

The advantages gained by the Stevens cut-off over the camboard cut-off were: Firstly, the saving of a portion of the steam in the space between the butterfly valve and the main valves; secondly, the use of two eccentrics allowed the lead of the exhaust valve to be greatly advanced, by which a quicker exhaust was obtained, and also the reversal of the strain on the piston at the end of the stroke was more gradual and with less jar on the bearings.

The Stevens patent, whether under the combined first and second claims or under the first claim alone, can be said to have been in universal and exclusive use on all beam-engine paddle-wheel steamboats in the United States since the expiration of the patent thirty-five years ago.

Of late years the substitution of the screw, with its quick-moving engine and slide-valve, has superseded the paddle and poppet valve on the ocean; and also in great part on the rivers of the Atlantic coast, and on the great lakes.

I add the following account of the early use of the expansion of steam and of the valves used on the Atlantic seaboard.

Watt, the creator of the steam engine for uses other than pumping, was the first to conceive the idea of utilizing the expansive action of steam in the cylinder when cut off from the boiler, and proposed it in a letter to Dr. Small in 1769 (see Farey's *Treatise on the Steam Engine*, London, 1827, page 339). He was also the first to put the idea in operation, which he did at the Shadwell Water Works in 1778 (Farey, page 341). He patented the application of this principle in his third patent, dated March 12, 1782, and in the specification and drawing clearly and beautifully illustrated by a diagram the principle of expansion (see Farey, page 347). He thereafter applied this principle to all of the single-acting pumping engines that he made, cutting off the steam by the main steam valve, and at from one-half to two-thirds of the stroke of the piston on the downward stroke, the pressure on each side of the piston being in equilibrium on the upward stroke (Farey, page 352).

But although Watt invented and patented the double-acting rotative steam engine in his second patent, dated 25th of October, 1781, and although he made many of these engines, of many different sizes, and was in fact the only maker

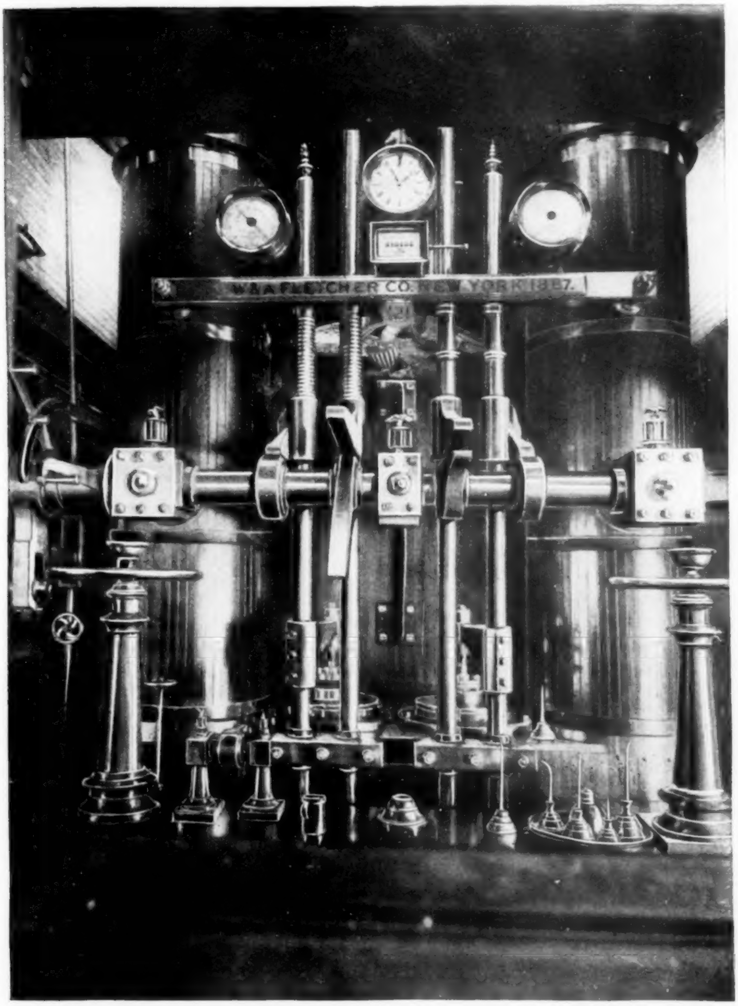


FIG. 104.—ENGINE FRONT, STEAMER "NEW YORK," HUDSON RIVER DAY LINE.

of them in the world during the long period that elapsed between their introduction and the expiration of his extended patent in the year 1800, he never used steam expansively on a rotative engine (see Farey, note *a*, at the foot of page 487). The engine that Fulton bought from Watt in 1805–6, and which he placed on the

Clermont in 1807, was operated by Watt's hand gear, as shown on Plate XIII. of Farey's *Treatise*.

It was very ingenious, but complicated, made almost entirely of steel tempered blue, and was operated by tappets and detents. No modification of Watt's hand gear, to enable it to cut off the steam on a rotative engine, was ever made by him or by others. The engines of all the numerous vessels that Fulton built were copies of the one he bought from Watt.

When about eleven years of age I frequently saw the steamboats *Fire Fly* and *Lady Richmond*, built by Fulton. Their speed was about four and a half miles an hour. I also frequently saw Watt's hand gear in operation; and remember on one occasion seeing the detents fail and the engine instantly stopped. No lead could be given by the hand gear; and the cranks were carried past the centres by

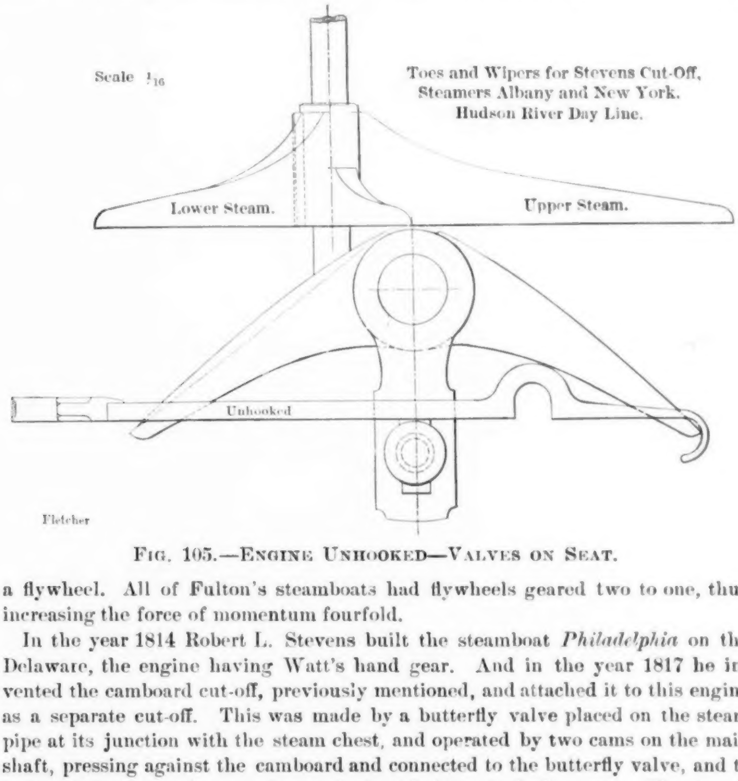


FIG. 105.—ENGINE UNHOOKED—VALVES ON SEAT.

a flywheel. All of Fulton's steamboats had flywheels geared two to one, thus increasing the force of momentum fourfold.

In the year 1814 Robert L. Stevens built the steamboat *Philadelphia* on the Delaware, the engine having Watt's hand gear. And in the year 1817 he invented the camboard cut-off, previously mentioned, and attached it to this engine as a separate cut-off. This was made by a butterfly valve placed on the steam pipe at its junction with the steam chest, and operated by two cams on the main shaft, pressing against the camboard and connected to the butterfly valve, and to a strong spring on its arm by a rod about half an inch diameter. The length of the cut-off corresponded to that of the cams, and the motion was exceedingly rapid. He at the same time increased the pressure from $2\frac{1}{2}$ to 10 pounds per square inch. This cut-off was very successful and remained in use on all low-pressure steamboats in this country long after the hand gear of Watt had been superseded by the eccentric of Murdock, and up to the introduction of the Stevens cut-off in 1840.

Yours truly,

MR. ANDREW FLETCHER. FRANCIS B. STEVENS.

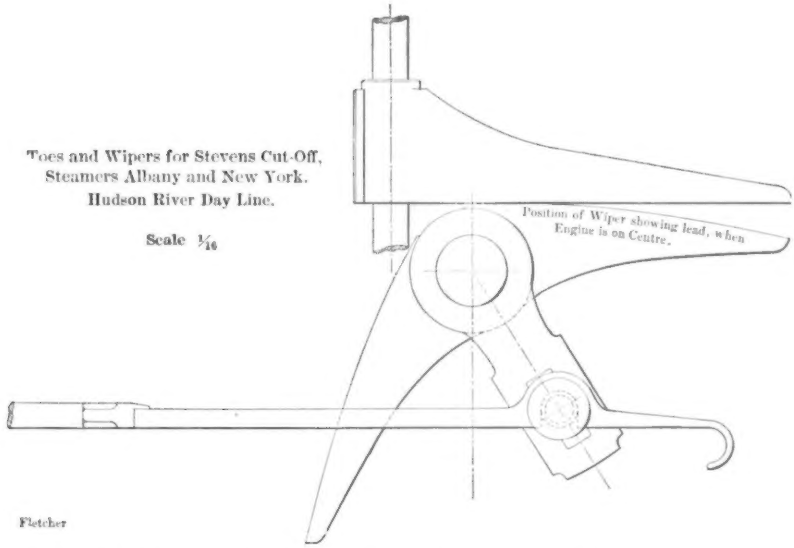


FIG. 106.—ENGINE ON CENTRE.—SHOWING LEAD AND POSITION OF WIPER.

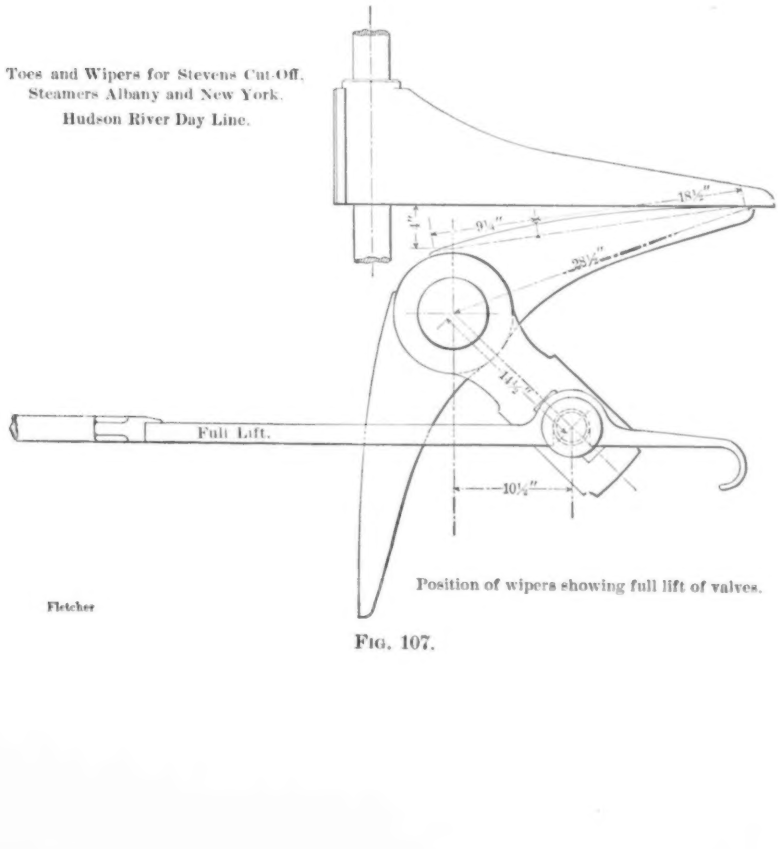


FIG. 107.

HOBOKEN, N. J., *April* 2, 1897.

MY DEAR MR. FLETCHER:

I also send the following account of the eccentric, deriving its motion from the shaft which superseded the plug tree, tappets, and detents of Watt, and was applicable alike to poppet and slide valves; and also add an account of the slide valve.

These were both patented by William Murdock, the foreman and partner of Watt, in 1799. The D slide is shown on Plate XVI. of Farey; and in another form, now generally used, by Fenton, Murray & Co., on Plate XVIII.

A notable circumstance in regard to the slide valve is that up to the year 1838, although it was then in universal use on the locomotives and marine

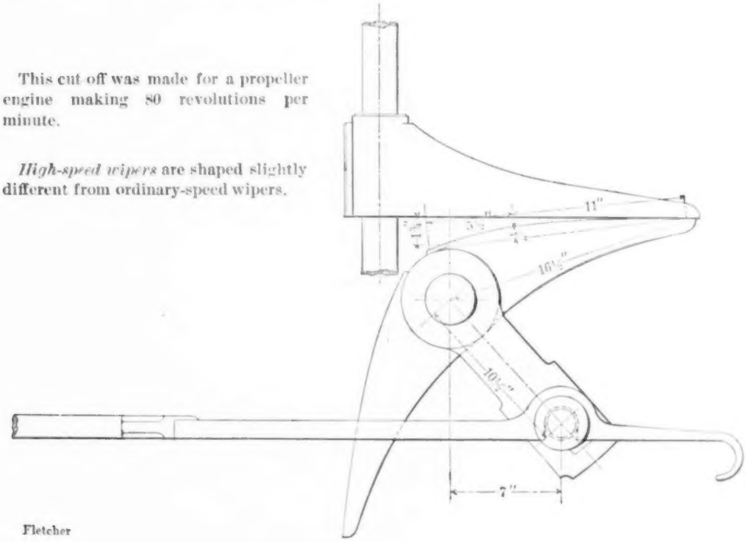


FIG. 108.

engines of England, and also on the locomotives of this country, it had only sufficient lap, or cover, as it was then called, to prevent the steam from blowing through the cylinder. The Chevalier De Pambour, in his famous treatise on the English locomotive in 1836, gives a drawing of the valves then in use on them, showing little or no lap; and although he writes very fully on the lead, he makes no mention whatever in his treatise of the lap or of its effect.

In the year 1838 the eighteen locomotives of the Camden & Amboy R.R. had one-sixteenth of an inch lap. In the same year the steamer *Great Western* made her first passage. Her engines had the D slide, with little or no lap, and carrying two and a half pounds pressure per square inch. She had a separate cut-off valve somewhat like the camboard, but it was never used, the low pressure of steam rendering it almost useless.

I have not met with an account in any publication, up to the year 1838, describing increased lap either in text or drawings.

The link motion was applied to the slide valve about that date. And in con-

FIG. 109.—STEAMER "ALBANY" (HUDSON RIVER DAY LINE).

Built, 1880. Hull of iron. Length, water line, 314 feet. Length over all, 325 feet. Beam, moulded, 40 feet. Beam, outside guards, 73 feet 6 inches. Depth of hold, 11 feet. Draught of water, 6 feet. Vertical beam surface condensing engine. Diameter of cylinder, 73 inches. Stroke, 12 feet. Feathering paddle wheels.

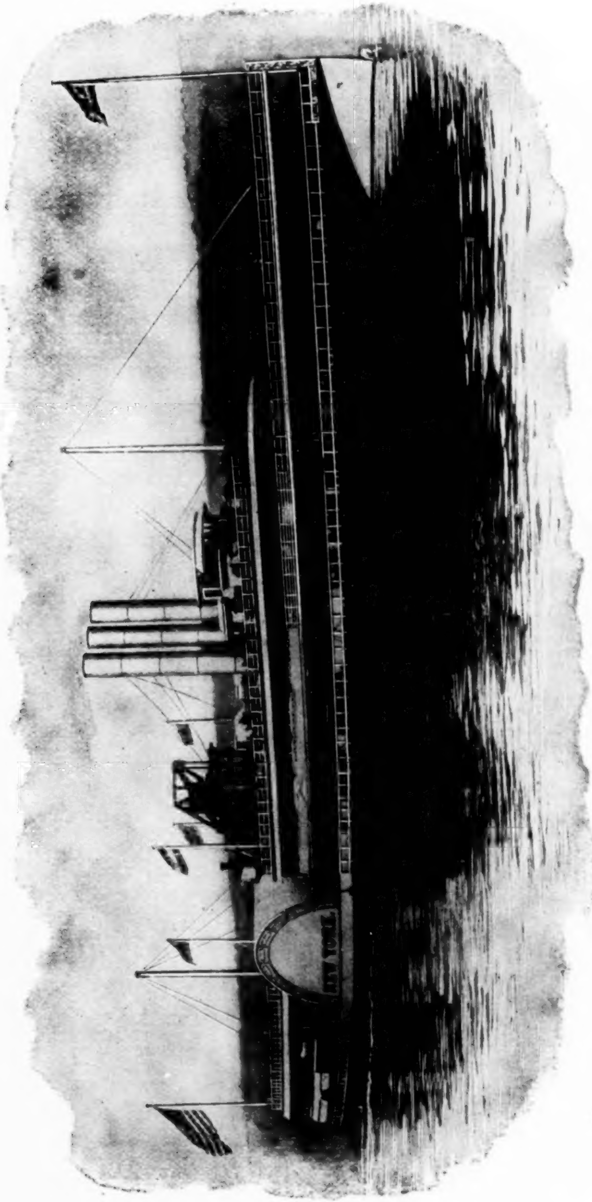


FIG. 112.—STEAMER "NEW YORK" (HUDSON RIVER DAY LINE).

Built, 1887. Hull of iron. Length, water line, 330 feet. Length over all, 341 feet. Beam, moulded, 40 feet. Beam, outside guards, 75 feet. Depth of hold, 11 feet. Draught of water, 6 feet. Vertical beam surface condensing engine. Diameter of cylinder, 75 inches. Stroke, 12 feet. Feathering paddle wheels.

junction with it, in the course of few years, the lap was gradually increased to its present extent, both liberating the exhaust in advance of the admission of steam and forming the efficient expansion gear in use on locomotives and screw steamers.

Yours truly,
FRANCIS B. STEVENS.

MR. ANDREW FLETCHER.

Our practice with the Stevens cut-off has included its installation on over two hundred steamers, new and old and large and small. We ascertain the amount of work required of the engine, and the necessary steam pressure, and then set the cut-off to suit. With the fixed cut-off, the owner need only notify his engineer of the steam pressure to carry with throttle valve wide open. This plan gives a steadier and more regular running of the boat upon its time table than will be secured from an adjustable cut-off, unless in competent hands.

Not long since the writer was upon a steamer in New York harbor, for which we had made a new cylinder and engine front in 1855, and had then applied the Stevens gear. It remains in good working order, and has given no trouble. With very fast-running engines, the wipers are made slightly different in shape, and we put springs on the lifting rods to force the toes to follow down the wipers. We have never had any trouble to make the cut-off work satisfactorily.

I do not wish to be understood as opposing adjustable cut-off gear. We have made and fitted a large number of engines with Sickels dash-pot cut-off with adjustable gear with most excellent results. But there are often advantages in having so simple an arrangement as the Stevens cut-off—to increase speed, increase pressure; to decrease speed, reduce pressure, or regulate throttle valve.

DISCUSSION.

Mr. Geo. I. Rockwood.—Perhaps it would be almost impertinent in me to discuss this paper from a technical standpoint, and, indeed, I do not care to discuss it exactly, but it suggests something to my mind which, perhaps, I might be allowed to present in connection with it. The poppet valve has always been, as everybody knows, a favorite form of valve on such engines. The poppet valve has been given a bad name in America by most stationary engineers, largely for reasons disconnected with technical con-

siderations, but one important technical reason is that it does not give a sharp cut-off. The poppet valve must be lowered to its seat carefully, otherwise it will "bring up" with a bang. In one form of valve gear that I have had to do with, there is no dash-pot provided for the cut-off valve, but it is lowered to its seat by a cam; hence the cut-off is very gradual, and in the case of the low-pressure cylinder of a compound engine having this valve gear, the cut-off cannot be discerned on the diagram at all. So I devised a modification of the valve, which may be old, but is not, so far as I know, designed to give a sharp cut-off. It is not generally known that the poppet valve may give as sharp a cut-off as the Corliss valve. What I did was to unite the piston valve with the poppet valve, providing a cup at the seats about an eighth of an inch deep, into which the poppet valve might fall, but finally stopping on its seat. If there is not virtue in the fit of the pistons, then we can rely on the virtue that is in the fit of the faces of the poppet valve. It works nicely without a dash-pot, as fast as 125 turns a minute.

Mr. L. R. Pomeroy.—At one time the boats of the Union Ferry Co., equipped with beam engines, had a detachable connection between the cams of the exhaust and the steam lifters, which would hold the steam valve open longer, or making the engine follow, practically, full stroke. This, we understood, was for emergency purposes only, such as working in heavy ice, etc. Noticing that recent engines of this type were not so equipped, raised the query in my mind as to the supposed value and reasons for doing away with such attachments.

Mr. Fletcher.—We have not put gags or trippers on our engines for many years. When we are allowed to, we always arrange to have a surplus of power over that needed in ordinary work. If the gags are not regulated properly, due to the difference in the leads and lifts of the steam and exhaust valves, a great deal of trouble could be produced very easily, valves would not seat properly, and the gags would be a detriment rather than a benefit. They require intelligent regulation. Mr. Stevens has always been opposed to them.

Mr. John C. Kafer.—I think that this paper is well worthy of record in the proceedings of this Society, as it gives a history of the cut-off mechanism of the beam engine, a type of engine which is particularly American. The lost motion in this cut-off gear corresponds to the lap on a slide valve. In reference to what the

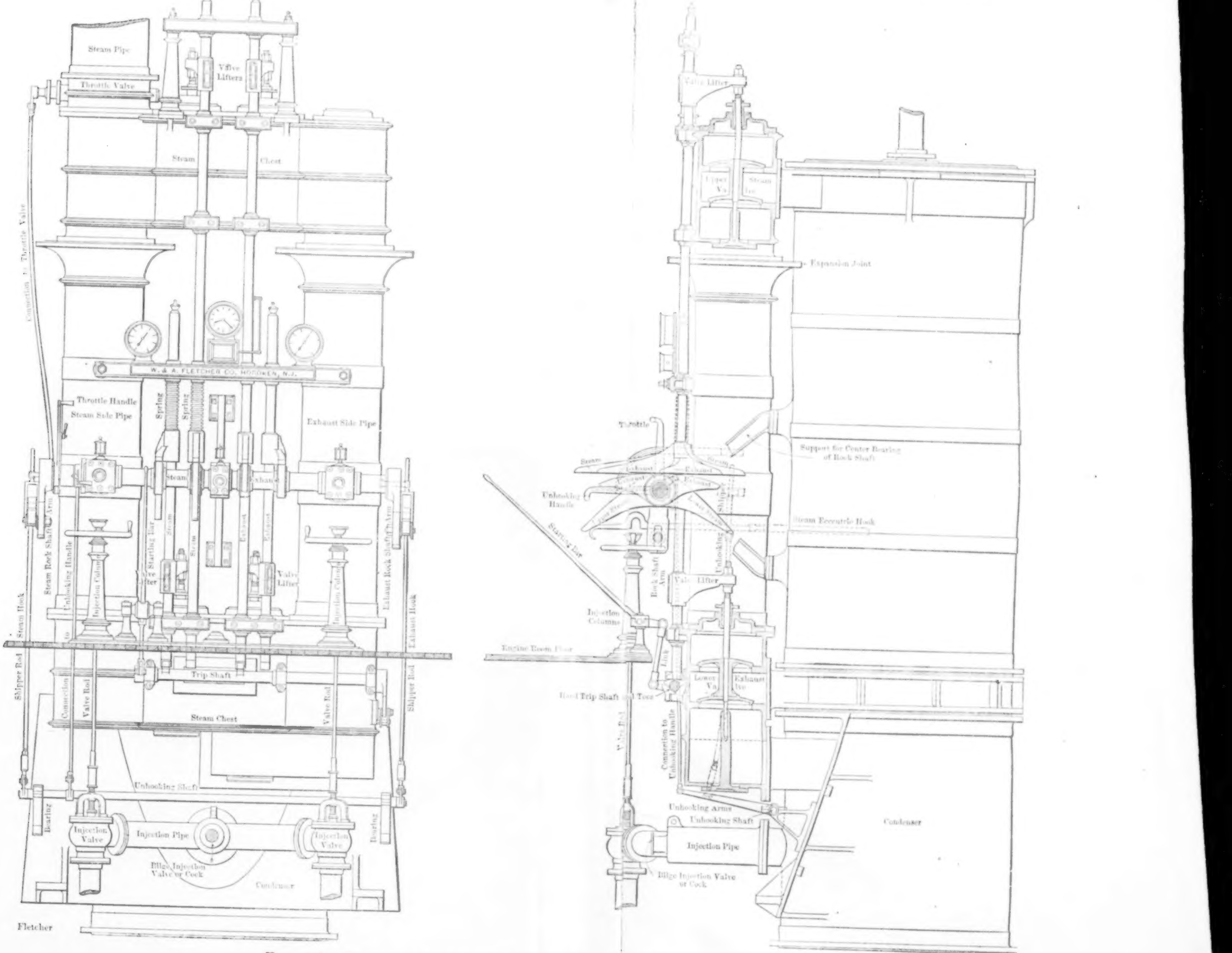


Fig. 110.—Stevens Cut-off Applied to Vertical Beam Engine.

Diameter of Cylinder, 73 Inches. Stroke, 12 Feet.

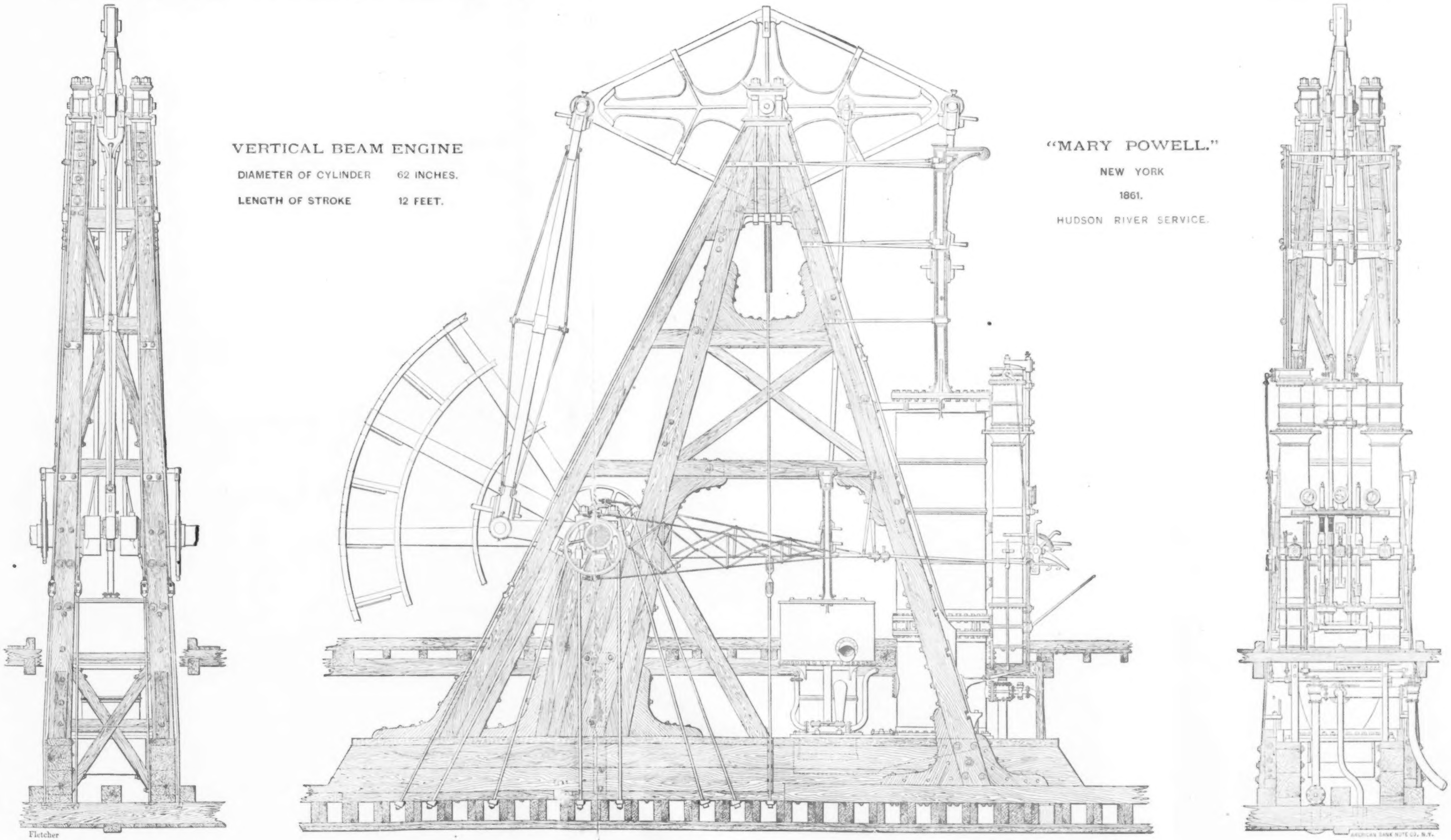

VERTICAL BEAM ENGINE
DIAMETER OF CYLINDER 62 INCHES.
LENGTH OF STROKE 12 FEET.
"MARY POWELL."
NEW YORK
1861.
HUDSON RIVER SERVICE.
Fletcher

FIG. 111.

speaker has just said about sharp cut-offs, we who deal with marine engines do not place much dependence on making a sharp cut-off. I do not see any advantage in it. There is no difficulty in lowering a valve slowly to its seat. We can lower it quite as easily without a dash-pot as with it. Referring to the dash-pot, which the last speaker mentions, McKay & Aldus built a little vessel with a dash-pot somewhat similar. Sometimes it dropped in the water and sometimes it did not. It was a single eccentric operating both exhaust valves and steam valves, so that the valve would have to drop from its highest point and would not follow farther than half stroke or full stroke. If the cut-off were thrown out altogether, it would have to follow full stroke. The record we have placed here is something I have never seen before. I have always wanted to know something about the early history of the Stevens cut-off, and I am very much pleased to know that Mr. Fletcher has placed it on record in this paper. I think that no criticism can be made on the Stevens cut-off, because its practical application for the last sixty years or more has demonstrated it fully, and I think that the newer plans Mr. Fletcher has shown are simply a modification of the old ones. As to the gags of the cut-offs that we used to have on low-pressure engines, it is necessary there sometimes to work up to a larger power, but they are not so much used now, because the boilers are too small. The steam in the boilers wouldn't last more than about two strokes. Now we can work off all the steam without the gags on the cut-offs.

Mr. Wm. Kent.—I would like to ask Mr. Kafer if he can use that cut-off at the speeds spoken of by Mr. Rockwood, up to 125 a minute, say.

Mr. Kafer.—I have known it to reach as high as 120, but it is not practicable; you must have a spring on top of the valve. The steamers *Hudson* and *Knickerbocker* had a cut-off with a poppet valve and a detaching apparatus. The detaching apparatus will not work quite as quickly as the Stevens cut-off. You can run a greater number of revolutions with the Stevens than with the detaching apparatus. There are other reasons why some other device is a little better to accomplish the purpose.

Mr. Fletcher.—I am sorry that Mr. Stevens is not here this morning, because he is a good talker and very interesting, and he could tell you about many experiments which he tried with both short and long cut-offs under various pressures of steam. The experience we have had with the Stevens cut-off has been very

satisfactory, and we have never found any trouble with it. When we know what work the boat is required to do, we set the cut-off, and set it for the given pressure of steam that they wish to carry; then there is no trouble whatever in doing the work and doing it well. It is very simple and substantial and lasting. I can talk of Stevens cut-offs being in use for over forty years—and that they are good yet, showing it is really a good valve motion. We have had some experience where we have tested between adjustable cut-offs and fixed cut-offs, and although I have no fault to find with adjustable cut-offs, for I like the Sickles cut-off, yet I have seen better performance with the Stevens cut-off set about half stroke, or less or over, depending on what was needed for the power, than when we had the adjustable cut-off. The reason was, I think, that the engineer did not handle the latter right. I have had to do with hundreds of engineers, and some of them are very careless how they handle the cut-offs, so that instead of working more economically with the adjustable cut-off, it has been the other way in many cases. I could mention cases where, taking the adjustable cut-off out and putting in a fixed cut-off, better results have been obtained with it.

Mr. Geo. N. Comly.—I would like to ask how high steam pressures are used in connection with the cut-off.

Mr. Fletcher.—With the ordinary low-pressure boats it is generally around fifty pounds for maximum, and for ordinary work or schedule time about thirty-five pounds of steam, but if it is applied to a compound engine, which we have done very easily, we carry as high pressure as we like. The very first compound beam engine that we built had the Stevens cut-off on both the high and the low pressure cylinders, and it works to perfection as far as we know, and gives good satisfaction. I might as well state that the boat we put the engine in is the *City of Fall River*, a freight boat running between Fall River and New York. The steamboat company were well pleased with her, and soon after they decided to build a second boat, and gave us the order for the engine. They wanted the same size of engine and same kind of boilers, and everything we thought would be the same. But soon after we had contracted, Mr. Sickles called to see us. He at that time had no business in hand and was well acquainted with some of the Fall River Steamboat people, especially with one of the largest stockholders, and he was very anxious to have the Sickles cut-off put in the new boat, the *City of Brockton*. We made no objec-

tion, because we liked it, and we thought it would be a fine place to try an adjustable dash-pot cut-off on a compound engine. Mr. Sickles told this gentleman, the large owner, that if he put his cut-off on the *Brockton*, being the same sized engine as the *City of Fall River*, that she would do the same work with twenty per cent. less fuel. Mr. Sickles wanted to carry twenty pounds more pressure than the *Fall River*, and alter the cut-off to suit. We got the order for the Sickles cut-off, and Sickles furnished us the drawings for all the details of the cut-off, and paid a great deal of attention to its manufacture. He was on hand a great part of the time when we were erecting the engine in the boat; was there the first time we got steam at the dock, and then on the trial trip, and also on the first trip from Fall River to New York, and was quite pleased, but he was called out of town soon after. After the boat had run for about a week or so, I had a talk with the chief engineer, and told him that we had been paying particular attention to the quantity of fuel she was burning. She was running well and making about twenty minutes' quicker runs than the *Fall River*, but she was burning a great deal more coal; and I told him what Mr. Sickles said: that he was going to save twenty per cent. on fuel. I said, "We will have to get you to come down on the fuel, because we have got to please the company." He said there had been no fault found with him. At the same time I said, "It is all very well for you to run a week or so fast and get a good name for the boat"; but advised him to reduce his cut-off and study fuel economy, and he said he would. But he did not come down for a long time. We talked to him a great many times about his burning more coal all the time, when he should be burning less, there being a great deal in the theory of short cut-offs and high steam. I am telling all this because I wanted to say that they did not handle the adjustable cut-off right. He had run for three months' time, when I sent my son Andrew to make a trip on the boat, and he took indicator cards and figured the horse-power developed, and proved to the engineer that he was using more power than was needed to make his time, and that he was burning about twenty per cent. more fuel than he should, and that we would have to correct that. My son set the cut-off adjusters on the boat so that she developed the same horse-power as the *Fall River* and she then came down to the same fuel, and ran a few minutes faster even then—four or five minutes faster than the other

boat—but that, we considered, was due to a little change in the model of the boat. I could tell of other steamers the same way, in which we changed from the adjustable cut-off to the Stevens cut-off and had better results. At the same time I am a great believer in an adjustable cut-off. I believe in many cases it is necessary; I could tell of places where we have used it. When we built the big *Priscilla's* engines we put the Sickles cut-off on the high-pressure cylinders, and the Stevens cut-off on the low-pressure cylinders. They could and can gauge her nicely to a fraction by just regulating the quantity of steam for the high-pressure cylinders. If they want twenty-one turns or twenty-two turns or twenty-three turns per minute, they have only to regulate the cut-off on the high-pressure cylinders. We were particular to get that right. I might tell also how they ran steamboats on the necessary time by changing the cut-off. On the Hudson River the steamboat *Armenia* was a good, fast boat. She had a Stevens cut-off, and after some years the owner had an adjustable attachment put on her valve gear, so that she could cut off a little short of half stroke or up to about three-quarters of the stroke. She was afterwards bought by Mr. Alfred Van Santvoord, who is the present owner of the Hudson River Day Line, and he put her on the route to Poughkeepsie, and thought that she would do her work. She made very irregular time and he was not pleased with her, and it was necessary to drop two of her landings, Cornwall and Milton. She did not make her time even then, and he was displeased. He told me that he wanted me to make a trip on that boat to Poughkeepsie and back again, and to notice just how they ran her, but not to say a word to the engineer or to the fireman or captain, or to any one, why I was on the boat. He said he did not like the adjustable arrangement for fear that the engineer was fussing too much with it. I made the trip, and that was just what I found. The engineer kept steam up to about forty pounds, and he would watch his gauge a good deal. If steam was going down he would cut her off short; if going up he would follow farther, but he would say nothing to the fireman. I said not a word to him; but when we returned I told Mr. Van Santvoord how she ran and what time she made, and all about it, and he told me to take out all the traps and throw them overboard, and set the Stevens cut-off at a point that I thought would do the work right; and so I altered her at once, and set the cut-off at the point that I thought would be right. Mr. Van Santvoord then told the engineer to carry thirty-

seven instead of forty pounds, and that was the only order he gave to the engineer. The next morning he asked me to go up with her again and see how she would go. I did so; and she made a good run, first-rate, kept the steam up, and had no trouble. Then Mr. Van Santvoord was pleased with her. After making the second or third trip, he told the captain to take up the two landings again, Cornwall and Milton, and she then made all the regular landings, and made regular and better time and burned less fuel. It was just because they attended to business. All the orders the engineer gave to the fireman in the morning was, "The boss has told us to carry thirty-seven pounds of steam; now, you attend to your business and do that, and for me to run with a wide throttle." For the ordinary side-wheel steamboats the Stevens cut-off has been the best thing we have ever put on. In many cases the engines are sometimes a little scant in power, and then they cannot turn good, steady wheels without cutting off in the neighborhood of half stroke. I could tell you some things that the *Mary Powell* and other boats did, but I think I had better not take up any more of your time.

Mr. James G. Winship.—I would like to add, in connection with Mr. Fletcher's remarks, some experience of my own in regard to cut-offs, and to relate a story: It was my fortune to be the engineer of a steamer with a beam engine with a Sickles cut-off. The engine was built in New York, and put in a boat on Lake Erie, called the *City of Buffalo.* The engine was fitted with Stevens cut-off. It was taken out of that boat and brought to New York and put in an ocean-going steamer, called the *Morro Castle*, and a Sickles cut-off was substituted for the Stevens cut-off. The same engine is now in the steamboat *Grand Republic*, running in this harbor, and is now fitted with Stevens cut-off. The boilers on the *Morro Castle* were small, and the engine had a jet condenser. We fed salt water in the boilers, which necessitated a constant feed and blow-off, so that when we would clean fires we had to cut off very short to maintain a steady pressure of steam. The captain came in the engine room once and said he wanted to know how it was that we could always have twenty-five pounds of steam, when the ship would sometimes go like the devil, and at other times she would just crawl, and all the time you have twenty-five pounds of steam. I started to explain to him that it was on account of the adjustable cut-off, when he said, "Damn the cut-off," and left me.

Talking about poppet valves, a great deal of loss is due to the difference in expansion between the chest and valves. In that old engine we never could tell about the condition of the valves, unless we took the hand-hole plate off the steam chests, and tested the valves while the chest was hot. The valves and seats were then made of brass—I believe Mr. Fletcher now makes both seats and valves of cast-iron. Then, another thing, both with the Sickles cut-off and with the Stevens it is easy to lose steam. If you have a Sickles cut-off and want to have the valve seat without noise, ten to one the valve does not seat, but fetches up on the water in the dash-pots, and with the Stevens cut-off the valve may be held off the seat by the toes. I was taught when a boy to see that the valve stem was loose in the lifter when the valve was seated.

The old Stevens cut-off is a good thing. When we used to go down the bay, a friend of mine on another ship would go down with us, but he could beat us. I asked, "Donegan, how far can you follow?" He said, "Eleven feet." His engine was eleven feet stroke. "How far do you generally follow?" "Oh, about three feet," he would say. He had gags fitted to his cut-off.

DCCLXX.*

ELECTRICITY IN COTTON MILLS.

BY W. B. SMITH-WHALEY, COLUMBIA, S. C.
(Member of the Society.)

ELECTRICITY as a means of transmitting power has been considerably dealt with in several very able papers before this Society; and it is not my purpose to take up valuable time in covering again ground which has been only too well and ably investigated, desiring to give only the results of my experience with electricity as a means of transmitting power in a cotton mill. Its many useful dispositions have been described fully, but in every case we lack direct comparison from actual practice, which would picture it to us in its true commercial light. It is the purpose of this paper to attempt to describe from the actual operation of two plants working under as nearly identical conditions as two manufacturing institutions can—the one operated by rope transmission with heavy head shafts, sheaves, etc., and the other by means of motors distributed throughout the building. In one the actual operation of the steam engine is considered; in the other the current is supplied to the motors from the secondary switchboard or receiving station.

Many have considered electric transmission in the light of a source of power, and we often hear comparisons on it with regard to power costs which are very misleading. Some have been imprudent enough to assert its economy for power purposes in connection with uneconomical water-power plants, as the means of making such developments commercially available; and several large plants for cotton mills have been developed on this line with such blindness as to their true commercial value from an economical standpoint that room is left for well-founded scepticism of their true value when compared with the many other more economical installations which might have been effected. Electricity's true position, for power purposes, is that

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

of a transmitter; and whatever the source of power, the point to be considered is its efficiency in connection with that source for transmitting purposes. Having settled that, our investigation then leads to its comparison with other well-known methods of transmission.

For the purposes of this paper we will take up the investigation, by tabulated data, from the actual every-day operation of the plants. The period during which the conditions as regards the working load were approximately the same was between the 1st of April and the 25th of June, 1897, and we shall designate the two plants as No. 1 and No. 2. No. 1 is a steam-driven mill, having a steam plant geared up with ropes, heavy head gearing, and large tapering shafts as such plants are usually geared up in the best practice of to-day. The steam engine is an 800 horse-power Corliss cross compound, built in 1895, with cylinders 20 and 40 by 60 inches stroke, and a rope wheel 24 feet pitch diameter, grooved for 26 $1\frac{3}{4}$-inch ropes, weighing 35 tons. This engine is being operated at an exceptionally low cost per horse-power for steam. There were in the mill during the period for which comparison of power is made 11,776 spindles and 720 looms; all the spindles and preparatory machinery were run full, but the looms did not average more than 682 per day. No. 2 is an electric-driven mill which rents its current from a central station and distributes it through a continuous-reading wattmeter to four 150 horse-power inverted motors bolted to the ceiling in convenient locations for economical distribution of the power, and belted to the shafting. The mill has been in operation since the 1st of January, 1897. This mill had in operation during the period named above, on an average, 12,448 spindles, with preparatory machinery, and an average of 356 looms out of 500 in the mill. The weight of the shafting in the steam mill is approximately 136,000 pounds, and in the electric mill 122,000 pounds.

POWER IN EACH MILL.

From the diagram (Fig. 114) showing the power curves in the two mills during the period alluded to, we find that the average in the steam mill is 535.71 horse-power for all purposes (this mill is only partly filled with machinery, and is using not quite two-thirds of its full power). From indicator cards taken, we find that the power required to drive the shafting and belting on

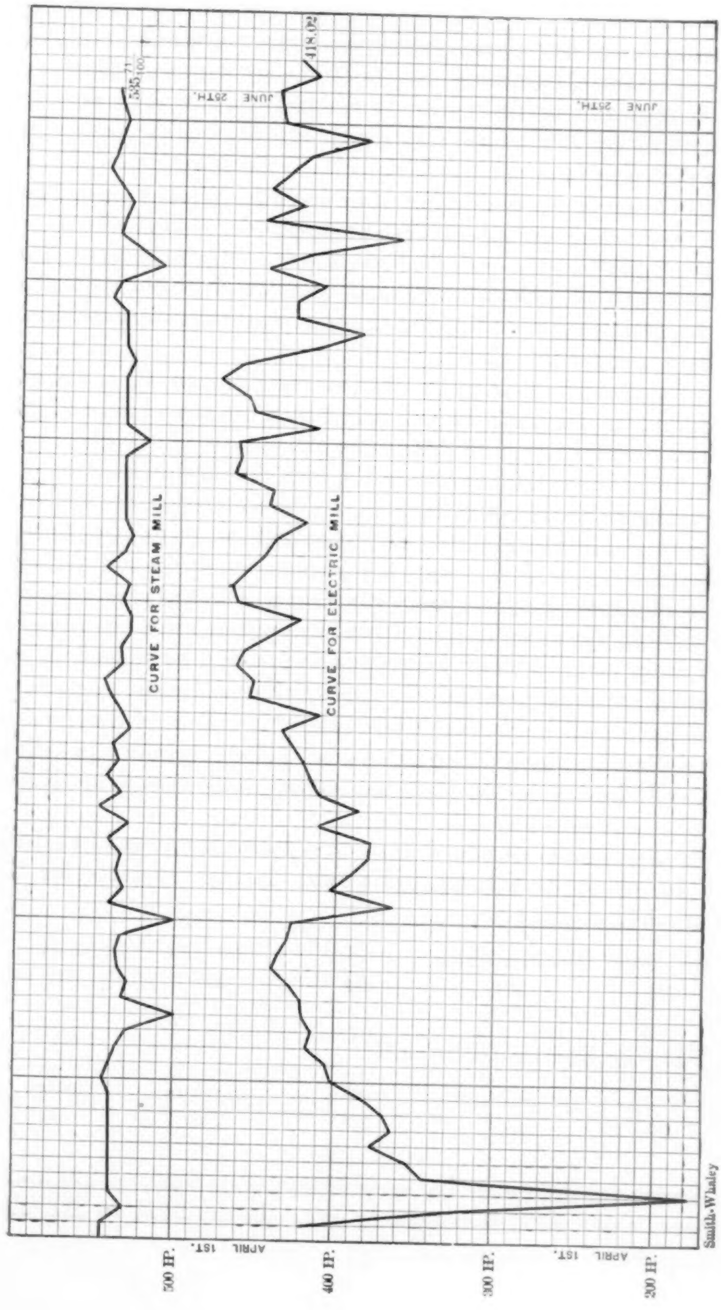

CURVE FOR STEAM MILL
CURVE FOR ELECTRIC MILL
585 71/100
418.02
JUNE 25TH.
APRIL 1ST.
500 HP.
400 HP.
300 HP.
200 HP.
Smith-Whaley

FIG. 114.

loose pulleys only is 228 horse-power; for the 720 looms and shafting, only 349 horse-power; and for the whole mill, 595 horse-power. Deducting the friction horse-power from the power required to drive the looms and shafting and dividing this result by the number of looms, we obtain the power required to drive one loom, which is 0.168 horse-power.

Deducting the power required to drive the looms and shafting from the total power gives us 246 horse-power, which is the power required to drive the spindle and preparatory machinery. This amount divided into the number of spindles gives us 60 spindles per horse-power, including the necessary preparatory machinery for this number of spindles.

At the time the data given above were obtained, there were in operation in the mill 14,848 spindles, with the necessary preparatory machinery, and 720 looms.

In the electric mill, owing to the lack of suitable instruments for testing the separate motors, we were unable to find the amount of power expended in friction, and consequently, having only the average power consumed, we can compare the mills by using the data obtained from the steam mill to bring the electric mill to the same basis. From the power chart we observe that on an average 418.2 horse-power per day were used in the electric-driven mill during the period above alluded to, namely, from the 1st of April to the 25th of June. During that period there were in operation on an average 12,448 spindles per diem and 357 looms, as against the steam mill operating 11,776 spindles and 682 looms.

From the data obtained from the steam-driven mill we have the following distribution of power during the test—for the steam-driven mill:

Total power.	Looms and shafting.	Friction.	H.-P. spds.	Looms.
535	340	226	196	114

and for the electric-driven mill:

Total power.	Looms and shafting.	Friction.	H.-P. spds.	Looms.
418	206	149	208	60

Hence the difference between 226 horse-power and 149 horse-power, which is 77 horse-power, must be credited to the electric mill in its present condition.

The following points from the foregoing can be stated as existing under the present conditions: The steam mill is operating under a disadvantage of an underloaded engine; the electric mill is operating under the disadvantage of driving more shafting per motor than it will when the full complement of machinery is installed.

The steam mill requires more supplies in the shape of oil, sizing for ropes, and other necessary incidentals due to the method of transmitting the power. The electric mill has cost nothing for its motors in six months of operation, not even the necessity of putting oil in the bearings, which was simply renewed once in that time as a precaution. The convenience of operating any section of the mill *ad libitum*, without reference to the other sections, is an advantage which is felt in dollars and cents in plants using the electric transmission.

The question which arises as to whether a generator directly connected to an economical type of engine to produce the power would consume the difference in the frictional horse-power, is one which can only be answered from data from institutions having such plants. It is the author's opinion that this difference of power would not be exceeded, and he hopes subsequently to give more specific data from further experiment from the actual operation of these two plants under better conditions, viz., when both mills are completely filled with machinery and motors and engine run at their full load; also in obtaining the efficiency of direct connected engines and generators.

It must be borne in mind that, unlike a machine shop and other manufacturing establishments, where a large amount of shafting is required to cover the ground and where intermittent power is used, a cotton mill drives in useful effect 95 per cent. of its shafting and uses actually in continuous operation almost the maximum power at all times.

In presenting this paper the author hopes that it will awaken enough interest in others to induce them to collect and present to the Society useful data which they may have relative to this very important subject.

DISCUSSION.

Mr. Wm. Kent.—This seems to be another case of cause and effect, such as was spoken of in discussing the so-called electric feed-water purifier. The supposed cause is not the real

cause. I think this saving of 77 horse-power in the electric-driven mill, while no doubt coincident with the installation of electricity, was not due to the electricity, but to something else. There are two mills about alike, and four lines of shafting for driving. In one case, in the steam-driven mill, we have an engine belted or roped to four lines of shafting, and we get 535 horse-power to do a given work. In the other mill the engine drives a dynamo, which furnishes current to four motors, one on each of the four shafts. Is it conceivable that 77 horse-power can be saved out of 535 by the simple change from direct rope or belt driving of the four shafts to driving them indirectly through an electric generator and four motors? I would like to ask the author how the horse-power is determined in the two mills. We generally take the steam power in a mill as the indicated horse-power in the steam-engine cylinder. Then there are the dynamometric horse-power at the flywheel and horse-power transmitted to the pulleys. Which of these horse-powers is it that he means by a horse-power? If he means horse-power at the ends of these shafts then I would like to know how he determined it. If, on the contrary, it was not the horse-power at the shafts, but the indicated horse-power, then the comparison does not seem to be correct, because the horse-power in the electrically driven mill apparently is measured on the wires leading to the motors, which is less than the horse-power that drives the electric generator. If, in the case of the steam-driven mill, it is the indicated horse-power, and in the other mill the horse-power measured by the electric current at the motors, then the saving of 77 horse-power is accounted for. But if there is a difference of 77 indicated horse-power apparently caused by the simple substitution of electric driving for belt driving, then we must look for some other cause, such as that in one of the mills the shafting was probably lined better than the other, or that a better lubricant was used.

Mr. Chas. T. Main.—As stated in the paper, neither of the mills under consideration is fully equipped, and therefore the friction loads as given do not represent the proper relation which they will bear to the total powers required to run the mills.

Assuming, as is stated, that the steam-driven mill will finally use about 50 per cent. more than its present power, the total required to run the mill will be about 800 horse-power. The

friction load will be slightly increased also, but assuming for the present that it will not be, it would amount to about 28 per cent. of the total. This is too large for a modern cotton mill and I do not think that any definite conclusions can be drawn until the mills are fully equipped.

With a new mill properly arranged, where the power is transmitted directly from the engines onto the head shafts in the various rooms where it is used, the friction load, with the belts on the loose pulleys of the machines, including that of the engine, should not be over 20 to 25 per cent. of the total load required to run the mill. The friction load is increased as the power is required to be transmitted through larger distances, and around corners before being used.

A large amount of information bearing upon this subject has already been printed in the *Transactions* of the Society. In vol. vi. the paper by Mr. John T. Henthorn, and the discussion of the same by Mr. George H. Barrus, give the friction loads of over sixty mills. In vol. vii. there is a paper on the same subject by Mr. Samuel Webber.

A part of the friction load becomes useful work when the belts are shifted from the loose onto the tight pulleys of a machine, so that the actual loss by friction with all the machinery running should be less than 20 per cent. Some engineers add to the power required to run the machinery one-seventh, to get the total load.

The various tests which I have made confirm the figures given above.

At present the transmission of power by electricity cannot compete with direct transmission in cotton mills as usually run, for there are in each case certain losses which are the same; viz., the friction of the engine and of the shafting, omitting the head lengths. With the direct transmission there is the loss in the friction of belts or ropes, and that of the head lengths, which is more than offset by the losses in generator, transmission, and motor in the electric drive, which is probably nearly or quite as much in actual practice as the total friction load should be with direct transmission. There is also against the electric transmission its extra cost of installation.

For some particular cases, and other kinds of work than textile mills, there is no question of economy of electrical transmission.

Prof. R. C. Carpenter.—Arranging the data as given on page 470 on the basis of *a*, that the total power delivered to shafting equal to 1,000 in each case, we have—
For the steam-driven mill:

Total Power.	Looms and Shafting.	Friction.	Horse-Power Speed.	Looms.
....	442	274	558	168
1,000	637	423	367	213

For the electric-driven mill:

Total Power.	Looms and Shafting.	Friction.	Horse-Power Speed.	Looms.
....	...	...	558	168
1,000	493	357	497	143

Decrease in friction due to use of electricity: { 66 horse-power. 6.6 per cent. total power.

To offset this there will be the loss of conversion and transmission of the electric current. Remarkably good results are obtained if we get 80 per cent. efficiency for dynamos and 90 per cent. for motors, or 70 per cent. as the total efficiency of transformation and transmission. To meet this condition the steam engine must deliver about 300 horse-power more when electricity is used; so that we have in this case an example when 300 horse-power is expended to save 66, or, in other words, when reduced to the same basis, the cost of transformation of mechanical into electrical power, and back again into mechanical, is several times that of the extra loss in friction due to use of the steam engine.

I am inclined to believe that such a negative saving will often be found, especially in the case of factories where the machinery is in nearly constant use; on the other hand, the electrical power will show more economical results when the machines are used infrequently or at short intervals during the day.

*Mr. W. B. Smith-Whaley.**—Mr. Kent seems to think that the electric mill is running its own generating plant. The paper distinctly states to the contrary—that the power is measured at the receiving station on the meter, after being transformed. Whatever losses accrue between the generating station and the meter, the mill has nothing to do with. It is a question as to whether these losses would exceed a gain apparently in the transmission in the mill.

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* Author's closure, under the Rules.

As stated in the paper, the causes for this gain are—first, the subdivision of the power at suitable points; secondly, a greatly reduced weight of shafting and the complete annihilation of all large belts.

In the steam mill, power was measured at the engine by means of indicators; in the electric mill it was read from the meter, and these were the units used.

The balance of discussion does not cover the ground stated in the paper, because the object of the paper was to present facts as nearly as possible as they existed under the conditions of operating the two plants, and distinctly raises the point as to whether it would be possible for the saving represented by the method of transmission used in the electric mill to be exceeded in frictional horse-power by direct coupled engine and generator.

With regard to Mr. Main's discussion, we can say that it will take about 850 horse-power to drive the steam mill when it is fully equipped. As was stated in the paper, all the shafting is in for the complete mill, and the friction of 226 horse-power, as given in the paper, represents the power used for all other purposes otherwise than driving the cotton machinery when doing work. In this there is in each plant about 10 horse-power in pumps, of which no account has been taken, and this would reduce the frictional horse-power that amount.

When the mill is completely filled with machinery, the horse-power will not increase to quite 10 horse-power. The author estimates about 8½ horse-power. Assuming that it will reach the full 10 horse-power deducted for the pumps, still gives us a figure of 226 horse-power, which is about 26 per cent. of the total power ultimately required to drive the full mill. Of course, this includes driving all loose pulleys on the machines.

The author agrees with Mr. Main that the transmission through generators and motors is very nearly the same in friction as direct transmission; but from reliable figures in the author's possession, taken from plants actually constructed, and from estimates from reliable machinery builders, the extra cost of erecting a steam generator and putting in the motors is very nearly the same as installing the plant direct with belts or ropes, and the gain in flexibility due to the electric plant is certainly a great advantage.

With regard to Professor Carpenter's discussion, I would say that he is very much in error in proportioning the different

powers in the mill. All we need say is, that in a 1,000 horse-power mill the power would be distributed as follows:

Total Power.	Looms and Shafting.	Friction.	Spindles.	Looms.
1,000	416	248	584	168

There is in this friction the same allowance for pumps as in the paper, no deductions having been made for it. Professor Carpenter labors under the same misapprehension with regard to the generating plant as Mr. Kent does; and, as stated in the reply to Mr. Kent's discussion, I will simply say that the author cannot assert exactly what power would be consumed in driving the generator to operate a plant of this size, not having any data at present to cover these cases, and distinctly leaves it an open question in his paper for further consideration by those having such data in their possession.

DCCLXXI.*

THERMODYNAMICS WITHOUT THE CALCULUS.

BY GEORGE RICHMOND, NEW YORK CITY.
(Member of the Society.)

In giving, by request, a brief outline of the method of treating heat relations, which, on account of its extreme simplicity, is coming more and more into general use, it must not be supposed that there is any disposition to undervalue the importance of the higher branches of mathematics. The contention is simply that the use of the calculus is no more essential to an intelligent use and understanding of such thermodynamic problems as ordinarily concern the engineer than it is necessary in order to find the horse-power of an engine from the indicator diagram. This diagram, in fact, affords a most striking illustration of the advantage of graphical representation, not only in fixing our ideas, but also in facilitating calculations. A mere inspection of it conveys an amount of information which, if clothed in mathematical formulas, would be unavailable to many, and perfectly intelligible to few, if any. Conversely, we may expect that when the heat relations we are accustomed to see expressed in formulas are presented in graphical form, they will be very much more intelligible. Results are thus rendered available to the non-mathematical reader, and an almost equal benefit accrues to the mathematician.

Since the indicator diagram is so familiar, and as every change of position on it is accompanied by the addition or removal of a definite amount of heat, it would at first glance seem very convenient to represent these heat changes on this diagram itself. Rankine, indeed, pointed out that the mechanical equivalent of the heat transferred to or from a substance, in passing from the condition represented by one point on the indicator

* Presented at the New York meeting (December, 1897) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

diagram to another, was represented on the same diagram by the area included between the line joining these points and two adiabatics drawn to infinity, one through each of them. He does not seem to have recommended this as a practical means of representing heat areas, for which it was obviously ill-adapted, but, in view of the fact that Rankine divides with Clausius the honor of elaborating the conception of entropy, it is astonishing that he failed to see the advantage of a diagram on which temperature and entropy are the coördinates.

If, instead of referring to a diagram * in which neither of the quantities involved were represented otherwise than as mathematical abstractions, he had used them as coördinates, the temperature-entropy diagram would have now been in use for forty years; incalculable labor would have been saved, and the confusion of ideas connected with entropy would have been impossible. As a more practical method of representing heat changes, Rankine suggested a pressure which he writes as p_h and defines as pressure † equivalent to expenditure of available heat. He did not make any practical use of it, and the only graphical result left us by Rankine in his text book is a mere picture.‡

Professor Cotterill, however, elaborated Rankine's idea with considerable enthusiasm, and under his treatment the quantity p_h served as the means of obtaining a variety of useful results.‖ Having undoubtedly obtained all that was to be had from exploiting this idea, Professor Cotterill admits, with admirable candor, that it is less available for the purpose than the temperature-entropy diagram, which he uses to a certain extent.

Professors Ayrton and Perry, § recognizing the importance of supplementing the indicator diagram in their investigations on the gas engine by concurrent information as to changes in temperature and heat supply, proposed another method of indicating these variations on the indicator diagram itself.

For the purpose of representing the interchange of heat

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* *A Manual of the Steam Engine and other Prime Movers*, 13th ed., par. 265, 266, and 267.

† *Ibid.*, p. 400. ‡ *Ibid.*, p. 408.

‖ *The Steam Engine Considered as a Thermodynamic Machine.* James H. Cotterill, 1890.

§ *The Gas-Engine Indicator Diagram.* Ayrton and Perry, *Philosophical Magazine*, 1884, vol. ii. An excellent description of this method will be found in Robinson's *Gas and Petroleum Engines*, April, 1890.

between steam and the cylinder walls, Dwelshauvers-Déry * devised still another method of supplementing the indicator diagram by heat areas. Probably other examples could be found, but these are sufficient to indicate the desire for some method of graphical representation of heat changes. This being the main purpose of their introduction, it is irrelevant to compare their relative merits and originality. They have not been used to any great extent by others than their originators, which, however, is not in itself a proof that they are not adapted to the special cases that called them forth.

The temperature-entropy diagram, on the other hand, is to be found in nearly every text book on thermodynamics or allied subjects published within the last ten years, and, what is peculiarly significant, the more recent the edition, the greater the use made of it. It will be a surprise to many to learn that Zeuner uses it throughout in his masterly treatise,† and that more entropy-temperature diagrams are to be found here at this early date than in any similar subsequent publication. Unfortunately he uses them as illustrations only; his calculations are all analytical, and refer to the $p\ v$ coördinates. He recognizes the value of showing the results in diagrammatic form, but is indifferent to the fact that in many cases these results could be obtained with the same rigor by mere inspection of the heat diagram. A very little editing of this monumental work, which is at once our admiration and despair, would render it—or at least the greater and most important part of it—perfectly simple to those of us who find no comfort in differential equations. The most complete treatment of the subject hitherto published is to be found in the treatise of J. Boulvin.‡ In this case the results are obtained directly from the heat diagram, and very useful auxiliary diagrams are introduced, which have been recently reproduced with modifications by Professor Reeves. ‖

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* Dwelshauvers-Déry : *Étude calorimètrique de la machine a vapeur.* See also *Table of Properties of Steam,* by same author, *Transactions* A. S. M. E., vol. xi., 1890.

† *Technische Thermodynamik*, von Dr. Gustav Zeuner. Erster Band, 1887 ; zweiter Band, 1890.

‡ *Cours de Mécanique appliquée aux machines* 3^{me} *fascicule théories des machine thermiques.* J. Boulvin, Paris, 1893.

‖ *The Entropy-Temperature Analysis of Steam-Engine Efficiencies.* Sydney A. Reeve, 1897.

In the English language we find a brief account by Professor Cotterill, as already mentioned, and a much fuller treatment by Professor Ewing.* This latter treatise may be unreservedly commended to all who wish to study the subject on these lines.

It appears that the claim, frequently made, of first publication in this country is invalid, since Belpaire preceded Gibbs by about twelve months. The following list of writers who have used it prior to 1890 may be useful for reference:

1872. Belpaire, Thomas: *Bulletin de l'académie royale de Belgique*, vol. xxxiv.

1873. Gibbs, F. Willard: *Transactions of the Connecticut Academy of Science*, vol. ii., page 309.

1875. Linde, Carl: *Theorie der Kalteerzeugungsmaschinen.*

1883. Schroeter, M: *Zeitschrift des Vereines Deut. Ing.*

1884. Hermann, G.: *Die Graphische behandlung der mechanischen Wärmetheorie.*

1887. Zeuner, Gustav: *Technische Thermodynamik, erster Band.*

1889. Gray, J. Macfarlane: Proc. Inst. Mech. Eng., and "Rationalization of Regnault's Experiments," paper read at Paris meeting, 1890.

This list represents the order of priority according to present information. It should really be headed by Carnot, followed by the names of Rankine and Clausius, which we prefer to bracket together under date 1854 rather than enter upon the merits of an unfortunate dispute. The results obtained by these two writers from the inspiration of Carnot rendered the work of the rest possible, and these results were left in a form so suggestive that the gap of nearly twenty years is a matter of surprise.

To Mr. Gray, although the last in the above list, must be awarded the credit for the popularity of the temperature-entropy diagram in England. The abstruseness of the subject obscured the simplicity of the tools he used in his paper, which many of us heard in Paris; but his application of it to simpler questions, and particularly the classic experiments of Willans,† in connection with which he freely used the heat diagram, served to bring out its manifold advantages.

The subject has not received in this country the attention it

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* *The Steam Engine and Other Heat Engines.* By J. A. Ewing, Cambridge, 1894.

† Willans on *Steam-Engine Trials*, Min. Proc. Inst. C. E., April, 1893.

deserves. A few writers, including Professor Carpenter and Professor Reeves, have recently made use of the temperature-entropy diagram, and it may interest the members to know that the first practical application of it appears to be found in the printed *Transactions* of this Society.*

The temperature entropy, unlike the indicator diagram, cannot be traced automatically, but it can be so easily constructed that we can conceive the tracing points linked together by such a mechanism that, while the ordinate of the $p\ v$ diagram is sweeping out areas representing work done by or on the substance, the temperature ordinate is concurrently sweeping out areas representing heat applied or heat removed.

In a closed cycle the pencil on each diagram will return to its starting point at the same time, and the two together will give a complete history of the transaction; the one will have traced a closed area representing either the net work obtained, or the net work done, while the closed area traced by the other pencil represents the net amount of heat missing from the system, or the net amount by which it is increased. The two areas are equivalent; the one representing in foot pounds, and the other in heat units, the heat that has been converted into work, or conversely.

The fact that these two areas are equivalent is an expression of the first law of thermodynamics, and for this purpose any coördinates fulfilling this condition would have answered. The choice of the absolute temperature as one of the coördinates is an expression of the second law. Take for example the familiar Carnot cycle bounded by two isothermals and two adiabatics.

The temperature-entropy finger of our supposed instrument would trace out a rectangle (Fig. 115) which is a complete heat record. Comparing point by point the two diagrams—

1 to 2, addition of heat at constant temperature: *isothermal expansion.*

2 to 3, reduction of temperature without addition or removal of heat: *adiabatic expansion.*

3 to 4, removal of heat at constant temperature: *isothermal compression.*

4 to 1, increase of temperature without addition or removal of heat: *adiabatic compression.*

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* Vol. xiv., p. 183. See also vol. xii., p. 874, *Effect of Steam Jacket on Cylinder Condensation.* W. W. Bird.

The quantity of heat added in passing from 1 to 2 is represented by a rectangle, whose height is the absolute temperature. The width of this rectangle is therefore the quotient of two known quantities. If, for example, the passage from 1 to 2 represents the evaporation of one pound of water at 80 pounds pressure, corresponding to an absolute temperature of 773 degrees and a latent heat of 896 thermal units, the width, or entropy, is $896/773 = 1.157$. If, on the other hand, a perfect gas is expanded at the same temperature isothermally from 1 to 2, we know that in this case the work done, as shown on the indicator diagram, is exactly equivalent to the heat supplied, as shown on the heat diagram. We also know that if r is the ratio of expansion, this work area is equal to $RT \log_e r$. This divided by 778, to convert it from foot pounds to thermal units, is the area of the rectangle, and its width must be obtained by dividing by T; that is, the width, or entropy, in this case, is $R \log_e r$.

It is thus seen that the dimension or quantity denoted by the term "entropy" is exceedingly easy to apprehend, and if introduced to us for the first time in this manner, it would be inconceivable that it could ever have been regarded as more or less mysterious. The difficulty comes not from the thing denoted, but from the connotation, which in this case is the validity of the second law. It is so important that the notion that entropy is a fictitious quantity, involving a peculiarly elusive idea, should be dispelled, that an illustration of the difficulty usually experienced may be permitted from another science. A young student is told that the resultant is the *sum* of two forces; the explanation of the term "sum" as here used seems perfectly rational and very simple, and he proceeds to combine or resolve forces (as indicated by lines) by the aid of his set squares only, with the greatest ease and confidence. The denotation is very simple; the connotation for him is zero. But to another man who has wrestled with half a dozen so-called proofs of the parallelogram of forces, and who has *argued* about the rationality of the vector notation, the connotation is considerable, and represents a mass of imperfectly resolved doubts.

But it is not sufficient that a thing should be simple; it must be shown to be useful. The claim in the present case is that the use of the temperature-entropy diagram renders the study of thermodynamics one of the easiest the engineer has to handle. A few examples only are necessary; and it would be manifestly improper to encumber the proceedings of this Society with a

treatise on thermodynamics, which, moreover, is entirely unnecessary in the present state of the art.

In the first place, most of the propositions relating to entropy, which seem rather elusive when referred to the $p\ v$ coördinates, are little more than truisms when referred to the $T\ \varphi$ coördinates. For example: (1) The entropy imparted in passing from

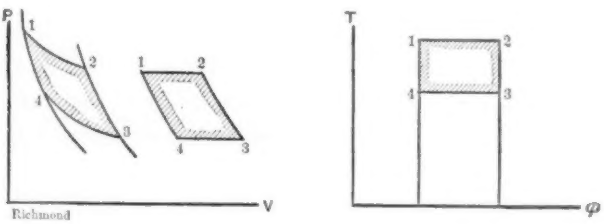

FIG. 115.

one adiabatic to another is the same by whatever path the passage takes place. This is equivalent to the statement that the distance between two parallel lines is everywhere the same.

(2) The heat absorbed or given out by a substance in passing from one state to another is given by the area between the curve representing the change of state and two adiabatics, one drawn through each extremity of this curve. (See Fig. 116.)

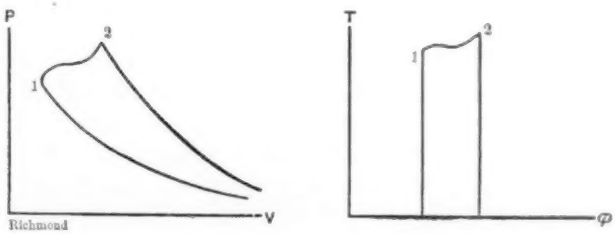

FIG. 116.

(3) If a series of equidistant isothermals be drawn between two adiabatics, they will cut off equal areas from the diagram. (See Fig. 117.)

(4) When heat passes from one body to another the entropy of the system is increased. For since heat passes only from a warmer to a colder body, the width of the resulting lower tempera-

ture heat area must be greater than the width of the equal but higher temperature heat area.

(5) The entropy of the world tends to a maximum. This is another way of saying that the tendency of heat is to settle down to a uniform level; each transfer, which must be downward, increasing the entropy.

(6) If two bodies have different temperatures, a portion of the heat of the higher temperature body can be converted into work by a suitable heat engine, the remainder being transferred to the colder body. The test that all the available heat has been transformed is that the entropy of the system has not been increased. If it has, the lost work is proportional to the increase of entropy.

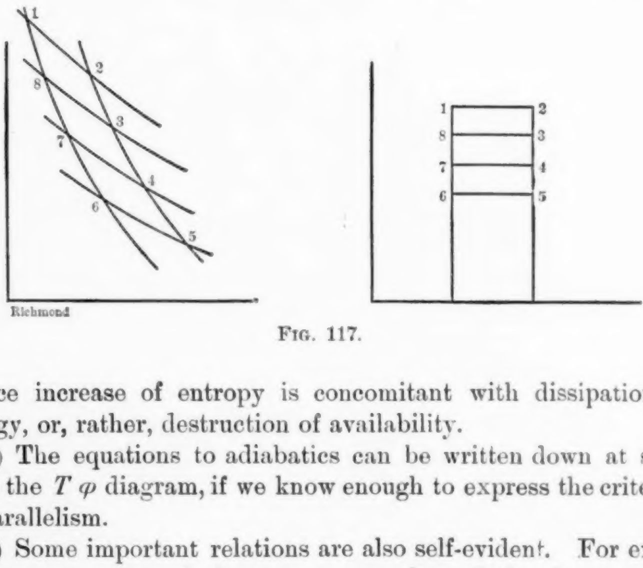

FIG. 117.

Hence increase of entropy is concomitant with dissipation of energy, or, rather, destruction of availability.

(7) The equations to adiabatics can be written down at sight from the $T\ \varphi$ diagram, if we know enough to express the criterion of parallelism.

(8) Some important relations are also self-evident. For example, suppose a pound of steam to pass through the Carnot cycle, with a very small change of pressure, and consequent very small change of temperature. The height of the figure being very small in proportion to its length, the $p\ v$ area, as well as the corresponding $T\ \varphi$ area, may be treated as a rectangle. (Fig. 118.)

If v be the specific volume of steam, we have $(P_1 - P_2)\,v = (T_1 - T_2)\,\varphi$, or

$$\varphi = v\,\frac{P_1 - P_2}{T_1 - T_2};$$

that is, if we have a table of corresponding pressures and tempera-

tures for short intervals, we can calculate from it the value of φ. Also, since the latent heat $L = T\varphi$,

$$L = Tv\frac{P_1 - P_2}{T_1 - T_2},$$

a formula from which the specific volume of a vapor is generally calculated.

It will now be shown how extremely easy the transfer of points from one diagram to the other is, choosing first of all the indi-

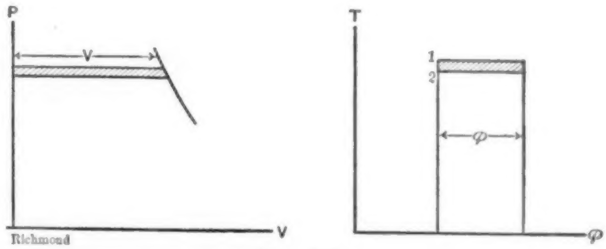

FIG. 118.

cator diagram of the steam engine, making, however, the expansion curve that of saturated steam (Fig. 118.), and assuming that there is no clearance.*

The diagram on the $p\,v$ ordinates requires no explanation;

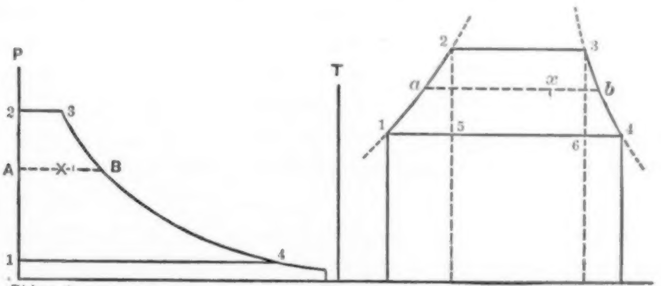

FIG. 119.

it is obtained by merely plotting the concurrent values of the specific volume and pressure as found in the tables. It is now usual to find in text books the tables necessary to construct the diagram on the $T\varphi$ ordinates.

The length 1–4 is the entropy of one pound of steam at the tem-

* Given nearly simultaneously by Clausius and Rankine as the first fruits of their conception of entropy.

perature T, and the length 2.3 that at the temperature T_2. We may proceed as follows:

Draw the isothermal line 1 4 of length as given by the table of entropy, and at a distance from the base equal to T_1, on the scale chosen, and complete the rectangle. The height of the line 2 3 is known, being T_2, and the position of the point 2 may be found from the table, as follows: The area swept out by a vertical line following the curve from 1 to 2 represents the heat required to heat the water from 1 to 2 prior to its evaporation at 2. The horizontal travel of this line is tabulated under the head of entropy of the liquid, usually written under Greek letter τ. The difference between its value at T_2 and T_1 is the length 1 5, through which we draw the vertical 5, 2 which determines 2; join 3 and 4, and the diagram is complete. If, instead of connecting 1 2 and 3 4 with straight lines, we wish to complete once for all the correct curves, it is only necessary to take a series of temperature intervals very close together, proceed as before, and then join the points thus found with a continuous curve. It is well to do this one's self on square-ruled paper.

These two areas bound our knowledge of the physical properties of the substance as given in the tables, and any point inside one area can be transferred to the other by the following simple rule:

Corresponding points in each diagram divide the horizontal lines through them in the same proportion.

For example: To transfer the point X from the $p\ v$ diagram to the $T\ \varphi$ diagram, draw a horizontal AB and through X, and also ab at the temperature corresponding to the pressure P_x. Divide ab in x in the same proportion as AB is divided in X, then x is the point required. The reason for this rule is sufficiently obvious. Neglecting the volume of liquid, the percentage of liquid evaporated along the line AB at X is AX/AB, and the same percentage is also ax/ab; hence these two ratios are equal.

Adiabatics on the $T\ \varphi$ diagram are verticals, and corresponding adiabatics can be drawn on the $p\ v$ diagram by the above rule. If the steam is dry as at 3, we see that after adiabatic expansion it is wet in the proportion 1, 6 steam and 6, 4 water. The percentage of dryness is 1, 6/1, 4. This percentage can be read from the figure, or taken direct from the table, for 1 6 is the sum of 1 5 and 2 3, both tabular values as well as 1 4.

It is apparent that if we have any one point on an indicator diagram for which we know the state of the steam, we can transfer the whole diagram to the $T\varphi$ coördinates, and read off on it the heat changes. A few easy exercises may be suggested. Boiler pressure being 80 pounds and exhaust into the atmosphere, then, excluding action of the cylinder walls :

(1) If steam is dry at the cut-off, how much moisture will it contain at the end of the expansion?

(2) If steam contains 15 per cent. moisture at beginning of expansion, how much will it have at 10 pounds pressure?

(3) If all water is turned into the cylinder, how much of it will be steam at 40 pounds pressure, at half stroke, at temperature of 240 degrees?

(4) Draw an adiabatic on the $p\ v$ diagram, by transfer from the $T\varphi$ diagram corresponding to initially dry steam, and to steam containing 10 per cent. moisture.

(5) If the steam is assumed to have initially 15 per cent. moisture, and to expand along the hyperbolic curve, draw this, transfer it to the $T\varphi$ diagram, and find how much heat the steam received or rejected during expansion.

(6) Assume in previous case that the steam is exhausted at 10 pounds pressure.

(7) Suppose case of steam pump and no expansion ; transfer diagram to $T\varphi$.

(8) What are termed the equations to the steam adiabatics really relate only to the $T\varphi$ diagram. Every purpose for which they are used is served by direct reference to it, and the equations in question are merely the algebraic statement that a pair of adiabatics are everywhere equidistant. For example, the equation to the adiabatic 3 6 is :

$$\begin{aligned} 2\ 3 &= 5\ 6 \\ &= 1\ 6 - 1\ 5 \\ \varphi_2 &= x\,\varphi_1 - (\tau_2 - \tau_1)\,; \end{aligned}$$

now, $\varphi_2 = \frac{L_2}{T_2}$, and $x\,\varphi_1 = \frac{x\,L_1}{T_1}$; and since the heat along 1 2 is proportional to the rise in temperature, 1 2 is a logarithmic curve, and the tabular value $(\tau_2 - \tau_1) = \log_e \frac{T_2}{T_1}$; hence the equation is:

$\frac{L_2}{T_2} = \frac{x\,L_1}{T_1}, - \log_e \frac{T_2}{T_1}$, and so on, with slight variation in form for an adiabatic drawn through any point.

If, after completing the evaporation at the point 3, further heat is added to the steam, it will be superheated; and, leaving the horizontal line, the temperature ordinate will increase in length in proportion to the heat added. After considerable superheating, the specific heat of steam gas may be considered constant, and the line 3 7 (Fig. 121) is a logarithmic curve, the entropy for a rise from T_3 to T_7 being $C \log_e \frac{T_7}{T_3} = .408 \log \frac{T_7}{T_3}$. The curve, however, if data are available, may be drawn and used to solve any problems involving superheated steam.

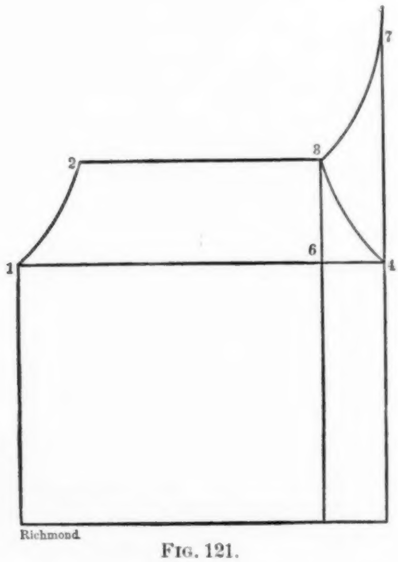

FIG. 121.

Refrigeration.—Similar diagrams may be used for the refrigeration cycle when a liquefiable gas is used. Under what is known as wet compression, the evaporation in the refrigerator is stopped at the point 6. The mixture is then compressed along the adiabatic 6 3, after which the gas is condensed, the heat being removed along the line 3 2 1; 2 being the temperature of the condenser, the heat of the liquid 2 1 is removed at the expense of the refrigerator, and must be deducted from the gross refrigerating effect, namely, the heat taken up along the line 1 6. When the liquid is fully evaporated in the refrigerator, the compression is

along the line 4 7, the gas being superheated to 7, then cooled and liquefied along 7 3 2, the work in each case being the closed area above 1 4.

Perfect Gases.—For perfect gases we have a much larger area of explored territory, and for every point where the characteristic equation

$$PV = RT$$

holds true, we can pass from one diagram to the other with the greatest facility. R being a constant, we obtain at once the value of T corresponding to any pair of concurrent values of $P\ V$ by simple arithmetic or geometrical construction. (Fig. 122.) We also know the rates at which heat is added when the pressure and also when the volume remain constant. These are the spe-

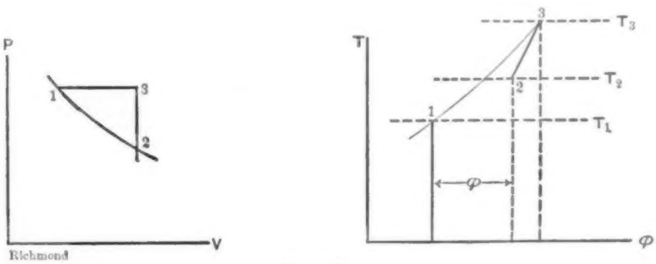

FIG. 122.

cific heats, which we will name m and n. We have seen that when heat is added at a fixed rate of m or n units per degree rise of temperature, the curve traced by the extremity of the travelling temperature ordinate is the logarithmic curve, and the entropy in passing from T_1 to T_2 is $m \log_e \frac{T_2}{T_1}$ and $n \log_e \frac{T_2}{T_1}$, respectively.

These being fixed curves, they may be cut out once for all and marked *constant pressure curve* and *constant volume curve*, respectively. All usual thermodynamic problems relating to perfect gases may then be solved on the drawing board. Suppose, for example, we wish to transfer the points 1 and 2 from the $p\ v$ coördinates to the $T\varphi$ coördinates, and thereby determine the heat imparted or removed in passing from 1 to 2 :

Draw a line of equal pressure through 1, meeting a line of equal volume through 2 in 3. Then T_1, T_2, and T_3 may be found by calculation, or by finding a fourth proportional to P, R, and

V, by construction. By these means we obtain the three isothermals, T_1, T_2, T_3. We may select the point 1 on T_1 at any convenient place, since it is only the *relative* positions of the points we desire. Then setting our *constant pressure curve* at T_1, we draw by means of it the line **1** 3; this determines point 3. Now take the *constant volume curve*, set it at temperature 3, and draw the line 3, 2. This fixes the point **2**. For an accurate determination of the amount of heat added or removed in passing from **1** to 2, it is necessary to take intermediate points tolerably close together, unless the line joining them is some determinate path. However, in the heat diagram the height is so very much larger than the width, that very little error is made in treating it as a trapezoid, and obtaining its area by multiplying its width (the change in entropy) by the average value of T.

We may note:

(**1**) If the point (**2**) falls to the right of (1) on the $T\varphi$ diagram, heat is added in passing from **1** to 2.

(**2**) If (2) lies to the left of (1), heat is removed in passing from (1) to (**2**).

(3) If 1 and **2** are on an isothermal, we should have found $T_1 = T_2$, and the point (**2**) would have been found by the same construction.

(4) If **1** and **2** are on an adiabatic, the line of constant volume would have intersected T_2 on the vertical through (1).

In applying this method to an ordinary indicator diagram a practical difficulty would be encountered, from the fact that the scale of the diagram would be variable. We can easily calculate the entropy in passing from (**1**) to (**2**), and thus avoid the necessity of using an auxiliary point (3).

The entropy, or distance between the two verticals, is obviously the sum of the projections of the curves 1 3 and 3 2, considering the latter as negative, since it is drawn backwards.

Now, the projection of the constant pressure curve 1 3 is $m \log_e \frac{T_3}{T_1}$, which may be written $m \log_e \frac{V_2}{V_1}$, since the pressure being constant during this period the temperature varies as the volume, and V_3 is the same as V_2.

The projection of the constant volume curve 3 2 is $- n \log_e \frac{T_3}{T_2} = n \log_e \frac{T_2}{T_3}$, which may be written $+ n \log \frac{P_2}{P_1}$, since the

volume being constant, the temperature is proportional to the pressure, and $P_3 = P_1$. Hence

$$\varphi = m \log_e \frac{V_2}{V_1} + n \log_e \frac{P_2}{P_1}.*$$

By means of this equation and the relation $PV = RT$, we can examine the heat changes of, for example, a gas-engine diagram. Such an examination of an actual diagram from a Hornsby-Akroyd oil engine is given below, the values of T and φ for ten points on the curve having been calculated.† (Fig. 123.)

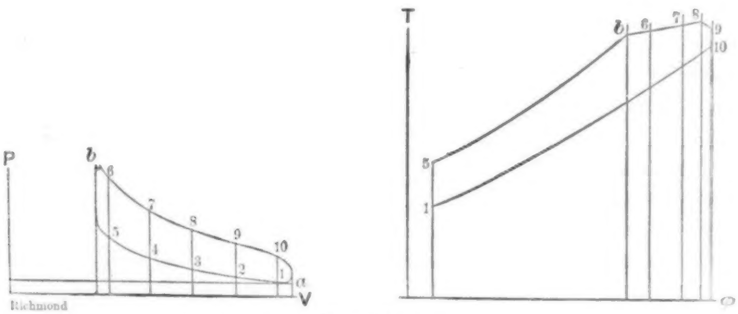

FIG. 123.

Some uncertainty attaches itself to the value to be assigned to m and n. By a process of approximation usual in this connection, and which cannot be far from the truth, the value of m has been taken as .246 on the compression curve and .26 on the expansion curve, while n is taken at .176 on the compression and .189 for the expansion curve. One of the conveniences of this method is the fact that we can draw our diagram to any con-

* If $\Phi = o$, both the points lie on the same adiabatic, and this expression is its equation. It may be written.

$$\left(\frac{V_2}{V_1}\right)^m = \left(\frac{P_1}{P_2}\right)^n$$

$$P_2 V_2^{\frac{m}{n}} = P_1 V_1^{\frac{m}{n}}$$

$P_2 V_2^k = P_1 V_1^k$, its usual form, and generally obtained by integration of a differential equation. It will be observed that the final integrations for elementary problems in thermodynamics are of the simplest possible character and can be avoided altogether on assumptions such as are quite usual, as, for example, in applying the hyperbolic curve to the indicator diagram.

† *The Oil Engine.* G. Richmond, *Transactions* Eng. Soc. of Columbia Univ., 1896-97.

venient scale without assuming any value for T. When subsequently a value is either ascertained by experiment or assigned, the scale of T may be written in the same diagram, and of course serve for any other value of T by simply noting the change of scale.

In the same manner ordinary logarithms may be used in calculating φ, and any convenient scale for plotting the results and for numerical results, the actual value of the entropy scale can be readily ascertained. From the table of values it is evident that the compression curve is practically an adiabatic, the slight accession of heat from the warm cylinder during the commencement of the stroke being compensated by the rejection during the latter part of the stroke, and both being too small to be shown on the heat diagram with the scale used. While the bulk of the heat is added at the time of the ignition, sufficient is added during the time of expansion to carry the expansion curve above an isothermal. The heat due to this retarded combustion is really very much greater than the figure shows, since, during this time, heat has been escaping through the walls. It is obvious, from the following table, that with careful measurement relatively very small additions of heat are measurable.

	PV	$\frac{T}{T}$	$.176 \log p + .246 \log v$	ϕ-ϕ
1.	475	1.000	6094	
2.	545	1.147	6149	—55
3.	600	1.263	6159	10
4.	661	1.391	6154	— 5
5.	706	1.486	6095	—59
			$.189 \log p + .26 \log V$	
6.	1391	2.928	6943	854
6.	1404	2.956	7045	102
7.	1438	3.027	7183	138
8.	1460	3.073	7268	85
9.	1428	3.006	7313	45
10.	1300	2.800	7308	— 5

The diagrams representing the theoretical heat relations in the various types of internal combustion engines are very easily drawn, and will, on the face of them, demonstrate the fallacy of a number of popular ideas, such as, for example :

(1) That the Carnot cycle has any significance, whatever, as a measure of the efficiency of the ordinary Otto cycle. It is not unusual to insert the enormously high temperatures obtaining in the gas engine in the ratio

$$\frac{T_1 - T_2}{T_1},$$

and from the result thus obtained argue that the gas engine is theoretically capable of utilizing 70 or 80 per cent. the heat supplied.

(2) That a Carnot cycle, if obtained, must necessarily be more efficient than the Otto cycle, with the same amount of initial compression.

(3) That the heat flowing into the jacket, if suppressed, would be converted into work. It would be seen that the effect would be to throw the bulk of this heat into the exhaust, where it belongs.

Obtaining Low Temperature.—It may be interesting to examine by this method the principles underlying the recently developed methods of obtaining very low temperatures.

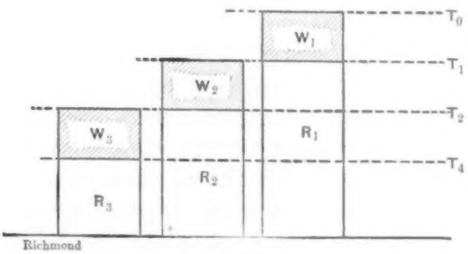

FIG. 124.

(1) *The Step-by-Step Method.*—The physical properties of the agents used preclude the possibility of using any one for an extreme range of temperature. By using several we obtain many of the advantages secured to the steam engine by compounding, together with the additional advantage of using the agent best suited to the particular range of temperature for which it is used. Assuming the Carnot cycle, we have first a machine which, by the expenditure of the work W_1, lifts an amount of heat R_1 from the level T_1 to T_0, where it discharges it, together with W_1, in the shape of heat. The heat R_1 may come from an insulated vessel which is maintained at the temp. T_1. A second machine, by doing

the work W_2, lifts the heat R_2 from the temp. T_2 to T_1 and discharges into the vessel from which W_1 lifts it to temp. T_0. W_3 in a third machine may be applied to lift the heat R_3 from T_3 to T_2 and discharge it into the refrigerator of the next machine, and so on.

(2) *Air Machine with Regenerator* (Fig. 125).—Air is compressed adiabatically from 1 to 2; it is cooled to its original temperature T_1 by removing heat along the line of equal pressure 2 3. It is then

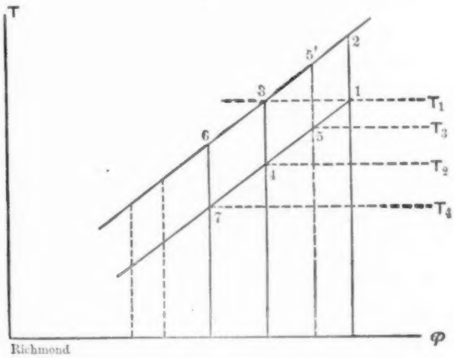

Fig. 125.

expanded along the adiabatic 3 4, reaching the temperature T_2. The cold air then takes up heat along the line 4 1. It can continue to receive heat only until some temperature intermediate between T_2 and T_1, since the refrigerator is always at a temperature lower than T_1. Let this be T_3, then the heat received from 5 to 1 is wasted. Theoretically compression could take place along the line 5 5_1 if the air were taken out of the refrigerator, but the impossibility of keeping the cylinder cool enough practically destroys this advantage. But by means of an interchanger, which, in this connection, is termed a regenerator, the heat from 5 to 1, instead of being taken from outside objects, may be utilized to cool the compressed air along the line 3 6, so that when expansion takes place along the adiabatic 6 7 the final temp. will be T_4, which is lower than T_3. This lower temperature heat can be used on the next trip to reduce still further the temperature at which the expansion takes place. Thus the effect is cumulative; but it must be observed that the expansion cylinder has to be kept colder and colder as the process proceeds, which puts a practical limit to it.

(3) *Air Machine with Regenerator and no Expansion Cylin-*

der.—It is well known that air is not a perfect gas, and Professor Linde has had the happy idea of utilizing this fact to abolish the expansion cylinder, and at the same time to utilize the regenerative effect to obtain temperatures sufficiently low to liquefy the air itself. If air were a perfect gas the heat discharged along the line 2 3 would be exactly equivalent to the work done on the air in the compression cylinder, and the heat received along the line 4 1 would be exactly equivalent to the work done by the air in the expansion cylinder. When a liquefiable gas is used, as we see by reference to Fig. 119, the work done in the compressor is a small part of the heat discharged, and the work done in the expansion cylinder is relatively so small as to be omitted.*

Now, in an imperfect gas there is present a molecular interaction, not sufficient to cause liquefaction, but when made active by pressure it is sufficient to transform a certain amount of heat. Thus the heat discharged along 2 3 is a trifle more than the equivalent of the work done, and the heat received along 4 1 is a trifle more than the equivalent of the work done in the expansion cylinder. This being understood, suppose the expansion cylinder suppressed, and the air allowed to rush into an insulated vessel. If we concentrate our attention on the issuing air we find that the work which would have been done on the piston is done on the air itself; it will be instantly cooled, the cooling being the equivalent to the kinetic energy of its motion as a whole. But in time it is brought to rest, this kinetic energy is reconverted into heat, and if it were a perfect gas its final temperature would be that which it had before being released from pressure. But being an imperfect gas, the molecular action set free by the release from pressure asserts itself, and heat must be supplied from the air itself to permit its operation. Hence, the final temp. is a little lower than T_1. In short, we have a certain initial refrigeration without the expansion cylinder. The nearer the air approaches the critical point the greater the molecular work, and the more rapidly the cooling proceeds. These facts also explain why the carbonic acid machines continue the refrigerating work after the critical point has been passed even when no expansion cylinder is used, the gas being very imperfect for temperatures near the critical point.

* See also notes on the refrigerating process. *Transactions*, American Society Mechanical Engineers, vol. xiv., p. 224.

It is hoped that the few examples, purposely drawn from familiar subjects, may serve to stimulate inquiry; and to facilitate such inquiry an effort has been made to present the "state of the art" up to date, rather than to impart a knowledge of the same.

DISCUSSION.

Mr. Wm. Kent.—It may be remembered that at the Hartford meeting of this Society last spring, I requested Mr. Richmond to present a little treatise on "Thermodynamics without the Calculus." I do not know of any discussion in the English language to-day which is suited for what might be called kindergarten stage of knowledge concerning this subject. I had trusted that he would not have been afraid to compromise the dignity of the Society, and that of its members, by an elementary discussion for the benefit of those of us who know little of vector quantities and denotations, and all that. I thank him for what he has done, and can only regret that he has presented the state of the art up to date rather than to have attempted to impart a knowledge which too many persons have had to go without.

*Mr. Geo. Richmond.**—The writer's attention has been called to the fact that Mr. W. W. Bird used the temperature-entropy diagram in a paper read before this Society, and mention has been made of it in a foot-note in its proper place. In this case the coördinates are reversed, but it goes to show that the adaptability of the method has forced itself independenly upon a number of investigators.

It has also been suggested that the method of transferring points from the indicator diagram to the temperature-entropy diagram could be further elucidated with advantage. For heat engines using a vapor very full details will be found in vol. xiv., pages 214 to 228. For gases the corresponding points on the temperature-entropy diagram are obtained from the well-known formulas:

$$T = \frac{Pv}{R} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

$$\varphi = C_p \log_2 \frac{V_2}{V_1} + C_v \log_2 \frac{P_2}{P_1} \quad . \; . \; . \; . \quad (2)$$

In place of the first of these any of the formulas giving the relation for imperfect gases may be used, as, for example, that

* Author's closure, under the Rules.

of Ledoux or that of De Volson Wood. In any case all the quantities on the right hand of the equations are known. In the case of vapors the principal lines of the diagram may be drawn once for all, but for gases it is better to construct it point by point. When studying the questions relating to perfect gases, C_p log N *φ* C_v log$_r$ may be cut out in wood and used as described in the text, but for the reason explained they cannot be used to transfer directly points from an actual indicator diagram, since the scales vary in each case. To construct these curves take any table of hyperbolic logarithms, plot for abscissas, the product of the log by C_p *φ* C_v respectively, the ordinates being in each case the natural numbers themselves.

PAPERS

OF THE

NIAGARA FALLS MEETING

(XXXVIIth)

MAY 31st TO JUNE 3d, 1897.

DCCLXXII.

PROCEEDINGS

OF THE

NIAGARA FALLS MEETING

(XXXVIIth)

OF THE

AMERICAN SOCIETY OF MECHANICAL ENGINEERS,

May 31st to June 3d, 1898.

THE convention of the American Society of Mechanical Engineers, at Niagara Falls, N. Y., was an interesting one, as being the first successful attempt on the part of the Society to conduct a meeting without incurring obligation on the financial side in the city where the convention was held. While there are interested and active members of the Society in Buffalo and the other cities of the western part of New York State, yet they were specifically and directly requested to permit the members of the Society to pay their own way and meet their own expenses. The Engineers' Society of Western New York, learning of the intention of the Society to hold a Niagara Falls meeting, appointed a committee to make arrangements for the pleasure and comfort of the Society, and to that committee great recognition is due for their interest in its details. Mr. W. C. Johnson, engineer for the Niagara Falls Hydraulic Power Company, was made the chairman of this committee of arrangement, but in all details of transportation and in the expenses of the reception, it was made possible for the pleasure of the members to be secured without the expenditure of money by their hosts. In this respect the Niagara Convention is a noteworthy one.

Mr. Johnson called the opening session to order and intro-

duced the Hon. Arthur Hastings, Mayor of Niagara Falls, who welcomed the Society to the opportunities of his city. This session and all the business sessions were convened in the assembly room of the Cataract Hotel, in which headquarters were conveniently located. After suitable reply by the President, Mr. Charles Wallace Hunt, who occupied the chair all through the meeting, the Society listened to a paper by Mr. Coleman Sellers, engineer for the Cataract Construction Company and the Niagara Falls Power Company, illustrated by lantern slides from photographs and drawings. Mr. W. A. Brackenridge, engineer for the company, also coöperated with Dr. Sellers.

SECOND SESSION. WEDNESDAY MORNING, JUNE 1ST.

This session was made the opportunity for business. It was called to order by the president at 10.30. The register in headquarters showed the following members in attendance:

Albree, Chester B.
Almond, Thos. R.
Angus, Robt.
Atwater, C. G.
Baker, F. D.
Baker, Chas. W.
Bartlett, G. B.
Barnaby, C. W.
Bates, A. H.
Beach, C. S.
Bellows, L. E.
Benjamin, Chas. H.
Bird, W. W.
Bole, Wm. A.
Bourne, S. N.
Boyer, Francis H.
Boyd, H. A.
Brown, F. G.
Brown, L. L.
Bryan, Wm. H.
Buchanan, A. W.
Bulkley, H. W.
Bump, B. N.
Burbank, L. S.
Camp, Geo. E.
Capen, Thos. W.
Carlton, Newcomb.
Cassier, Louis.
Cheney, W. L.
Christie, Jas.
Cloudsley, J. B.
Cogswell W. B.
Colvin, F. H.
Conant, Wm. L.
Conrader, R.
Cooper, H. R.
Cullingworth, Geo. R.
Detrick, J. S.
Dow, Chas. M.
Earll, Chas. I.
Fawcett, Ezra.
Fickinger, P. J.
Flinn, Thos. F.
Foster, Chas. E.
Fryer, Geo. G.
Gabriel, Wm. A.
Garfield, L. M.
Garrett, Wm.
Glenn, H. F.
Gobeille, J. L.
Granger, A. S.
Gray, Thos.
Griess, Justin, Jr.
Greene, C. E.
Guthrie, E. B.
Hand, F. L.
Hammett, H. G.
Hartness, Jas.
Haskins, H. S.
Henning, G. C.
Horton, Jno. T.
Hugo, T. W.
Hunt, Charles Wallace, President.
Hunt, F. W.
Hutchinson, J. A.
Hutton, F. R., Secretary.
Jacobs, Ward S.
Keep, W. J.
King, C. C.
Kirchhoff, C.
Laforge, F. H.
Lane, H. M.
Leitch, Meredith.
Lodge, Wm.
Low, F. R.
Lufkin, E. C.
Mackintosh, Frank.
Magruder, W. T.
Mason, H. I.
McBride, James.
McDonald, C. F.
McKechnie, R. R.
McLeod, Wm. C.
Meier, E. D.
Melvin, D. N.
Merrill, G. H.

Meyer, H. C.
Mesta, George.
Miller, F. J.
Morgan, C. H.
Morris, H. G.
Morse, C. M.
Neff, F. H.
Newhall, J. B.
Nicoll, C. H.
Otis, Spencer.
Parks, E. H.
Porter, H. F. J.
Quimby, W. E.
Reed, W. E.
Reeve, C. D.
Richards, C. B.
Richmond, Geo.
Richmond, K. C.
Rites, F. M.
Roberts, Wm.
Robinson, A. W.
Robinson, S. W.
Sabin, A. H.
Sawyer, Harry.
Scott, Geo. H.
Sellers, Coleman.
Serrell, Jno. A.
Sparrow, E. P.
Stanwood, J. B.
Stearns, Albert.
Stiles, N. C.
Suplee, H. H.
Sweet, Jno. E.
Taber, Geo. H., Jr.
Tabor, Harris.
Varney, W. W.
Wallace, D. A.
Wallace, Wm.
Warner, Worcester R.
Warren, Jno. E.
Watson, H. D.
Weeks, Geo. W.
Wellman, Chas. H.
Wellman, S. T.
Whittier, has.
Wiley, Wm. H.
Winther, C. A. G.

Pursuant to the usual policy, of reducing the routine business of the spring meeting of the Society to its lowest terms, the only two items of business presented were the notice by the Secretary, of amendments to the rules to be acted on at the annual meeting in November, and the report of the tellers of election.

Article 10 is to be supplemented by the addition at its close of the following:

"Applications for membership from engineers who are not resident in North America, and who may be so situated as not to be personally known to five members of the Society, as required in the foregoing paragraph, may be recommended for ballot by five members of the Council, after sufficient evidence has been secured which shall show that in their opinion the applicant is worthy of admission to the grade which he seeks."

And the sentence in that same article which now reads, "He must refer to at least five members or associates, personally known to him," is to be changed so as to read, "He must refer to at least five members or associates to whom he is personally known." The final sentence of the present article is to be similarly changed, and the words "personally known to him," are to be changed to "to whom he is personally known."

The report of the tellers of election, concerning the members seeking to join the Society at this convention, was read, as follows:

REPORT OF THE TELLERS OF ELECTION.

The undersigned were appointed a committee of the Council to act as tellers (under Rule, 13), to scrutinize and count the ballots cast for and against the candidates proposed for membership in

the American Society of Mechanical Engineers, and seeking election before the thirty-seventh meeting, Niagara Falls, N. Y., 1898.

They have met upon the designated day in the house of the Society, and have proceeded to discharge their duty. They would certify for formal insertion in the records of the Society, to the election of the persons whose names appear on the appended list, to their respective grades.

There were 439 votes cast on the orange ballot, of which seventeen were thrown out because of informalities (the members voting having neglected to indorse the sealed envelope).

JOHN C. KAFER,
GUS C. HENNING,
H. H. SUPLEE,
GEO. H. RICHMOND, } *Tellers of Election.*

ELECTED AS MEMBERS.

Ames, Jos. H.	Hitchock, E. A.	Reid, J. S.
Anderson, Robt. M.	Howard-Smith, S.	Replogle, Mark A.
Barth, C. G. L.	Hubbard, H. De F.	Roberts, W. B.
Benns, Chas. P.	Johnson, H. J.	Sargent, H. B.
Blackwell, J. L.	Leitch, Meredith.	Smith, Ephriam.
Bray, Thos. J., Jr.	Luther, F. S.	Sparrow, J. P.
Burbank, L. S.	Neff, E. H.	Stone, J. W.
Emrie, Almon.	Osgood, John C.	Tucker, E. D.
Greer, R. C.	Pease, Chas. S.	Tyberg, Oluf.
Grohmann, C. L.	Pessano, A. C.	Washington, Wm. De H.
Hanna, E. E.	Poole, Herman.	Williams, Thos. H.
Harris, J. F. W.	Reed, Wm. E.	Winand, P. A. N.

ELECTED AS ASSOCIATES.

Bellows, L. E.	Crouch, C. H.	Knight, H. S.
Berg, H. O.	Densmore, Edw. D.	Rogers, Chas. E.
Burnham, H. A.	Jones, C. R.	Waddell, Geo. F.

PROMOTED TO FULL MEMBERSHIP.

Bierbaum, C. H.	Norris, H. M.	Prosser, Jos. G.
Dewson, E. H., Jr.	Patitz, A. M.	Van Trump, Chas. R.
McCleliand, E. S.	Prather, H. B.	

ELECTED AS JUNIOR MEMBERS.

Allan, Percy.	Ennis, W. D.	Merrill, Geo. H.
Andrews, Wm. J.	Fisher, L. D.	Mott, Charles S.
Ball, B. C.	Frothingham, F. E.	Neuhaus, F. A. E.
Blair, A. W.	Gott, Jos., Jr.	Orr, A. M., Jr.
Broome, E. L.	Griess, Justin, Jr.	Sayers, Jno. H.
Chambers, F. R., Jr.	Harding, Adalbert.	Spillman, E. O.
Connett, L. R.	Hillyer, Geo., Jr.	Stevens, A. H.
Duncommun, Edward.	Jones, David T.	Wickhorst, Max H.
Ekstrand, Chas.	Massey, Geo. B.	Widdicombe, Robt. A.

On behalf of the Committee on Uniform Standards in Methods of Tests and Testing Materials, Mr. Henning reported that the experimental furnace for which certain members of the Society had subscribed the necessary purchase money, had been installed in the laboratories of Columbia University, and that with proper pyrometric appliances the committee was investigating the laws of contraction of cast iron and its expansion during the process of cooling. He stated that those points which were so clearly defined in Mr. Keep's paper on cooling curves, corresponded probably to points at which a rearrangement takes place in the iron itself of the elements composing it, especially carbon, and that these are the critical points which are somewhere at temperatures below 800 degrees. He hoped that at the next meeting a complete report connecting these points of recalescence in cast iron under rising and falling temperatures, as well as the behavior of wrought iron and steel of various carbons, can be presented to complete the series of reports which have already been made to the Society.

The Secretary made official announcement of the death of Sir Henry Bessemer, honorary member of the Society, at his home in England, on March 15th, 1898. It had been the desire and intention of the Council, that a memorial monograph in preparation by Mr. James Dredge, of England, should be presented at this spring session, which should thereby be made in a sense a memorial session in recognition of the services which the Bessemer inventions and machinery had done for mechanical engineering the world over. Mr. Dredge's plans had been frustrated, so that the text of the paper was not in hand for presentation at the meeting, but by direction of the Council it was presented by title in this way, with a view to its incorporation as one of the papers of this meeting, into the volume of *Transactions* for the current year.

The professional papers were taken up in their order, the Secretary reading the first paper, which was by Mr. Geo. H. Barrus, and entitled, "Plea for a Standard Method of Conducting Engine Tests," which was followed by Mr. Bryan Donkin's paper on "Extension of the Standard Uniform Methods of Conducting and Reporting Steam Engine Tests." The discussion on these papers was taken up jointly after the reading of the second one, and was participated in by Messrs. Stanwood, Carpenter, Magruder, Barnaby, Boyer, S. W. Robinson,

A. Wells Robinson, Meier, Henning, Christie, and Suplee. At the close of the debate, which had a distinct trend towards the advisability of appointing a committee to consider the subject, Colonel Meier, of St. Louis, arose :

Col. E. D. Meier.—I move that the Council be empowered to constitute or to appoint a committee of seven to take up this matter of uniform methods of conducting and reporting steam-engine tests, in the most general manner, as suggested by Mr. Barrus and Mr. Donkin ; and of course all the points brought up in debate can be taken up by the committee.

Mr. Gustavus C. Henning.—I second the motion ; only I would suggest that the number of members be reduced from seven, because in the work of other committees the assembling of such a large number has been found exceedingly difficult, and the work would progress if the number were reduced.

Colonel Meier.—I will amend my motion and make the number five. I think five would be a better number.

Mr. Henning.—It is simply a matter of expediency. With that amendment I second the motion.

The motion was carried.

A paper by Mr. O. C. Woolson, on " The Hanging and Setting of Fire Tube Boilers," was discussed by Messrs. Bissell, Le Van, Fawcett, Bryan, Wm. H. Barnaby, Boyer, Henning, Hugo, McBride, C. W. Baker, La Forge, Garrett, Suplee, Meier, Bird, and S. W. Robinson ; that by C. W. Baker, on " What is the Heating Surface of a Steam Boiler ? " being discussed by Messrs. F. W. Dean, Fawcett, Wm. H. Bryan, S. W. Robinson, Henning, Barnaby, Hugo, Meier, Garrett, Suplee, Bird, La Forge, McBride, and C. W. Baker, this being the final paper of that session.

At the close of the meeting the courtesy of the floor was given to Mr. Emile C. Geyelin, the veteran hydraulic engineer and expert in water wheels, who presented some facts concerning the propelling plant of the Niagara Falls Paper Company. The wheel-pit was described as wholly excavated out of rock, 156 feet deep, with a width of 42 feet 6 inches, and a breadth of 28 feet 6 inches. This pit receives its water from the inlet above the Rapids, and discharges at the bottom into a 7-foot tunnel. Three turbines, each of 1,100-horse-power when operating under a 140-foot fall, were started in 1893. Three additional wheels, each of 1,300 horse-power, were afterwards attached. These turbines are 4 feet 8 inches in diameter, and are calculated to

run at a speed of 250 revolutions. Each turbine casing has a 66-inch diameter valve gate, controlled by a hydraulic lift, whereby any one wheel can be shut off. The regulating gates of the wheel are controlled by a governor at the top of the pit. The weight of the vertical turbine shaft, 156 feet long and 10 inches in diameter, having at the lower end the turbine and the upper end a bevel wheel, is 66,250 pounds in each case. The water is introduced from below and counterbalances this weight when operating at full load, but on account of the violent fluctuation in resistance the usual thrust-bearing construction is provided, to allow for variations in the counterbalance. Firm bearings for the long upright shaft are secured by a series of steel frames, 21 feet apart. The turbines are of bronze, and provided with a series of grooves to reduce leakage of water. At the top of the vertical shaft the power is changed into horizontal motion, at a speed of 200 revolutions for three of the wheels, by means of mortise bevel wheels having 5¼ inches pitch and 20 inches face. The last three wheels have steel bevels, experience having shown that the average life of the wooden cogs at this speed did not exceed 2,640 working hours.

In addition to these six turbines the plant of the Niagara Falls Hydraulic Power and Manufacturing Company has recently installed 2,500-horse-power turbines under a total fall of 215 feet. These turbines are with horizontal axis connected directly to the dynamo which is to absorb the power.

Mr. Geyelin illustrated his remarks with elaborate blueprints.

Wednesday Afternoon.

The members this afternoon were the guests of the Cataract Electric Power Company, the Carborundum Company, the Niagara Falls Paper Company, and the Niagara Falls Power and Manufacturing Company. Parties were taken to the plant of the Cataract Power Company by a convenient line of street cars, and after visiting this great work in a body broke up into small parties, which visited the other points of interest. The shop of the Dobbie-Stuart Company was also open to visitors.

Wednesday Evening.

The parlors of the International Hotel were thrown open to the members and their friends, for a reception with dancing, followed by a collation. The President and the Chairman of

the Committee of Arrangements, with their ladies, received the members on entering, and an active floor committee made the evening pass pleasantly and brilliantly. The ménu had been specially devised, with interesting and flattering references to the events of the month in connection with the Spanish-American war.

Third Session. Thursday, June 2d.

The papers of the morning were by Mr. Jas. W. See, entitled "Patents," discussed by Messrs. Varney, Morison, Fawcett, Foster, Bates, C. W. Baker, Albree, and S. W. Robinson; by Mr. Wm. H. Bryan, on "Relations between the Purchaser, the Engineer, and the Manufacturer," which was discussed by Messrs. Meier, Barnaby, and Hugo; by Geo. A. Lowry, entitled "One Hundred Years of Ginning and Baling Cotton;" following the presentation of which paper Mr. Cleaver made some further remarks, and opened a bale of cotton which had been compressed by Mr. Lowry's press; by R. H. Thurston, on "Graphic Diagrams and Glyptic Models," and by Chas. L. Norton, on "The Protection of Steam Heated Surfaces," remarks and discussion on this paper being made by Messrs. Carpenter, Meier, Sweet, Robinson, S. W. Bates, Gobeille, Gray, Thos. Hutton, Suplee, Otis, and C. W. Baker.

Thursday Afternoon.

Arrangements were made by the local committee, whereby the members might purchase at special rates the complete series of tickets necessary for the excursion which was planned for this afternoon, to take in the Gorge. Crossing the newest arch bridge to the Canada side, the party was taken in cars of the Niagara Falls Park and River Railway up to Chippewa, and from thence back again down the river to Queenston. This gave an opportunity to see the lower river and the Whirlpool from the top of the bank. At Queenston a steamer conveyed the party across to the American side, and after a brief run from Lewiston down to Fort Niagara, on the lake, and back, the return trip up the Gorge on the American side was begun. At a point below the Whirlpool a stop was made to witness the shooting of the Rapids by a couple of Indians in their canoes, and the party returned to their starting point.

Thursday evening was intentionally left without assignment.

Closing Session. Friday, June 3d.

The session of Friday morning was opened by the announcement, by the Secretary, of the death of Mr. Chas. E. Emery, of New York City, member of the Society, and past vice-president.

It had been known that Mr. Emery had been taken ill quite recently with a form of heart failure, and his death occurred on Wednesday, June 1st. Brief reference was made to the work which he had done in the field of steam engineering, particularly in investigating the effect of cylinder condensation, in connection with the late W. P. Trowbridge, at the close of the war, 1861–65, at the Novelty Iron Works, and later, his work in connection with the Centennial at Philadelphia in 1876.

The president had directed a telegram to be sent to representative members of the Society in New York City, requesting them to form themselves into a committee and attend the funeral in a body.

The following papers were presented at this session: By Mr. F. J. Cole, on "Bending Tests of Locomotive Stay Bolts;" by Mr. J. E. Johnson, entitled "Note on the Carbon Contents of Piston Rods;" by Mr. C. H. Benjamin, on "Experiments on Cast Iron Cylinders;" two papers by Prof. R. C. Carpenter, one entitled "Mechanical Properties of Certain Aluminium Alloys," the other being in conjunction with Mr. P. J. Fickinger, and entitled "Method of Manufacture and Test of a New Seamless Tube." The paper on stay bolts was discussed by Messrs. Otis, Henning, and Sweet, the paper by Mr. Johnson being discussed by Messrs. Almond, Suplee, Henning, Souther, Sweet, Otis, and Robinson, and that by Mr. Benjamin by Messrs. Kent, Suplee, and Gray.

Messrs. Souther, Suplee, Baker, and Almond discussed Professor Carpenter's paper on aluminium alloys, while the last paper of the session, by Messrs. Carpenter and Fickinger, was discussed by Messrs. Souther, Henning, Baker, and Morgan.

Professor Hutton.—As a matter of business, Mr. Chairman, I would like to call the attention of the meeting to Article 31 of our rules:

"At the regular meeting preceding the Annual Meeting, a nominating committee of five members, not officers of the

Society, shall be appointed." The rest of the rule refers to the duties of the committee. It would be in order, therefore, that some one should move that a nominating committee should be appointed by the president, under Article 31 of the rules.

This motion being duly made and seconded, the president, after the adjournment, appointed the following committee:

Mr. W. R. Warner	Cleveland, O.
Mr. S. W. Baldwin	New York City.
Mr. H. G. Morris	Philadelphia, Pa.
Mr. H. A. Wheeler	St. Louis, Mo.
Mr. C. J. H. Woodbury	Boston, Mass.

While the meeting had been, in a sense, conducted by the members themselves and without incurring financial obligation, as has been said before, yet the hospitable intent of Niagara Falls and Buffalo, and the western part of the State, had not allowed the Society to escape from being the recipient of attentions and courtesies for which the Society desired to express its sense of recognition. This was done in the form of a report prepared during the meeting, and presented in the name of a Committee on Resolutions by the Secretary, as follows:

The American Society of Mechanical Engineers, concluding its thirty-seventh convention, in the City of Niagara Falls, desires to put on record the satisfaction which it feels in the conduct of a meeting at which it has been possible to enjoy so much of pleasure without incurring at the same time a burden imposed by a sense of financial obligation to manufacturers and residents in the city which entertained them. It is impossible, however, in adjourning, to escape the sense of indebtedness to engineers and others, by whose courtesy the details of the meeting have been so admirably carried out, and whose attention has given so much added enjoyment to a successful meeting.

The Resolution Committee therefore begs leave to present the following resolutions, and asks that the Society will ratify its recommendations:

Resolved, That the thanks of the American Society of Mechanical Engineers are due to the Hon. Arthur C. Hastings, Mayor of Niagara Falls, for the courteous and kindly words of welcome with which he greeted the arrival of the Society in Niagara Falls. It was the opening note of a meeting which the Society will long remember with pleasure.

Resolved, That the American Society of Mechanical Engineers desires to express to the Niagara Falls Power Company, to Dr. Coleman Sellers, and to Mr. W. A. Brackenridge, engineers of that company, its thanks for the opportunity

which was given to it for the full inspection of the stupendous undertaking which that company has laid out. They recognize the magnitude of the problem on its financial and on its technical side, and will carry away with it an earnest appreciation of the talent, the thought, the knowledge, and the skill which have been brought to bear upon the solution of the unique and almost insuperable difficulties which have had to be met and overcome.

Resolved, That in the visit which was permitted to the members of the Society at the Hydraulic Power and Manufacturing Company's plant, the members of the American Society of Mechanical Engineers enjoyed the opportunity to study a problem so different in its character and method of attack from that which has been presented in other places and under different conditions. The Society recognizes the great opportunity for growth and development which is offered where so great a quantity of water is available under such great heads, and will watch the outcome and the increasing development of the hydraulic motor under these exacting conditions, with growing appreciation. The members would like to include in this resolution their thanks to the Niagara Falls Paper Company, the Carborundum Company, and the firm of Dobbie-Stuart Company, for the opportunity to visit their plant during their stay at Niagara Falls.

The members of the Society desire to express to the proprietor and management of the International Hotel their thanks and appreciation of the careful attention to detail, whereby their reception on the evening of Wednesday was made so pleasant a feature of their stay in Niagara Falls. It means much of sacrifice to put the service and facilities of a great hostelry at the command of a group of visitors, and for the kindly and considerate way in which this was done, and for the attention which was paid to the visitors, the Society request that Mr. Samuel Greenwood and those associated with him will accept their hearty thanks.

It has been one of the most unique experiences of the Society in many years of successive conventions, to enjoy the opportunity which was presented to them in the afternoon of Thursday, for the ride on the Gorge Road and the Canadian Electric Railway. They desire to thank the companies concerned, in extending this pleasure to the members, for their admirable arrangements, and to congratulate them on the skill and care which have been manifested in the location, planning, and construction of their difficult undertaking. The afternoon was most thoroughly enjoyed and the Convention asks that Messrs. Ricker, Brooks, and their associates will accept the thanks which is their due. The Indians should not be forgotten.

Resolved, That the American Society of Mechanical Engineers, assembled in convention at Niagara Falls, desires to express to those corporations, firms, manufacturing establishments, and engineers in Buffalo who have extended to them the courtesies of an invitation to visit their establishments during the

Niagara Falls visit, its hearty thanks for the same, even if the pleasure of other opportunities has made it impossible to accept all the chances that have been laid before them. They desire particularly to include in this list Messrs. Riter & Conley; Tonawanda Iron & Steel Co.; Brooks Locomotive Works; Delaney Forge & Iron Co.; Buffalo Forge Company; Holly Manufacturing Company; Wagner Parlor Car Company; Lake Erie Engineering Works; Pratt & Letchworth Company; Buffalo Smelting Works; Buffalo Bridge & Iron Works; Buffalo Railway Company.

Resolved, That the American Society of Mechanical Engineers recognizes the interest in its convention which has been taken by Mr. Peter A. Porter and the management of the Cataract House in the success of their convention. Members would thank these gentlemen for the use of a convention hall without charge, and for the arrangements of headquarters, for which they are indebted to their care.

As soon as the Engineer's Society of Western New York learned that the American Society of Mechanical Engineers was planning a convention at Niagara Falls, they appointed a committee of coöperation, who should attend to the arrangements necessary for such a convention. Of this committee Mr. W. C. Johnson, engineer of the Niagara Falls Hydraulic Power & Manufacturing Company, has been chairman. The Society desires to express to this executive committee, and to its chairman in particular, its cordial appreciation and thanks for all that they have been instrumental in securing for the Society. The difficult burden of previous arrangement has been borne by this committee and its chairman with great skill and ability. This resolution is to convey, in a faint and unsatisfactory way, the recognition which the Society feels for that work.

The precedent has not been established as yet in the Society of Mechanical Engineers that the official meetings of the Society permit its lady guests to have the opportunity of saying what they would like to say, when they also have been included in the affectionate thought and interest of those in charge of a convention. It must be left, therefore, to those who are mere men to make themselves the mouthpiece for the expression of the thanks of the ladies for the courtesies which have been unintermitted during their stay in Niagara Falls. They ask that the committee of ladies who were in charge of the entertainment at the Three Sisters, and who have in so many other and almost unnoticed ways secured the comfort and pleasure of their visitors, will understand that this is a failure in the way of an attempt to express what the ladies would say of appreciation for the work of this committee.

These resolutions being duly seconded, and carried with acclamation, the motion to adjourn, being duly presented, was carried. The president gave the usual notice that the annual meeting was to be expected in New York City, beginning November 29th, and that the Council had given favorable consideration to a suggestion that they should select the city of Cincinnati, Ohio, for the spring convention of 1899.

The meeting then adjourned.

Friday afternoon was allotted to visits by individuals to points of interest in Buffalo. The weather during the meeting was perfection, and the manifold attractions of Niagara Falls were much appreciated by everybody.

DCCLXXIII.*

GRAPHIC DIAGRAMS AND GLYPTIC MODELS.

BY R. H. THURSTON, ITHACA, N. Y.
(Member of the Society and Past President.)

GRAPHICAL representations of relations of quantity are often employed by the draughtsman, the lecturer on physical science or engineering, and in scientific bookmaking, usually adopting a diagram of two dimensions. Glyptic methods of representation have been rarely used, except in such relief-models, from time to time, as particularly important geological work occasionally illustrates. The former class exemplifies the art of the geometrician applied to special purposes; the latter similarly applies the art of the sculptor to the reproduction of forms of a radically different sort.

The graphic representation of the relations of two variable quantities by the construction of a diagram having two rectangular co-ordinates, is as old, at least, as Aristotle. That great philosopher of Greece, over two thousand years ago, employed this system in his illustrations of the principles of economics and his doctrine of "reciprocation" of exchanges in commerce, by equivalence of current valuations. His case of the shoemaker and the builder is perhaps most familiar.† He places the producers and their products, between which exchanges are to be effected, at the four corners of a rectangle, and diagonal lines indicate the paths of transfer in exchange of the house of the builder for the shoes of the shoemaker and of the one product to the producer of the other, and thus exhibits "the acts of mutual giving in due proportion." Watt's indicator diagram is a curve in which the ordinates are the total steam-pressures and the abscissas the corresponding, simultaneous motions of the piston of the engine, both on conveniently chosen scales,

* Presented at the Niagara Falls meeting (June, 1898), of the American Society of Mechanical Engineers, and forming part of Vol. XIX. of the *Transactions*.

† Aristotle's *Ethics*, chap. 6.

while the enclosed area is a measure of the net work performed in the engine during the stroke represented. The laws of variation of pressure with piston movement in each of the several periods into which the cycle is divisible are thus graphically represented, and the equations of the several corresponding lines are the algebraic expressions of those laws. Watt employed the first of these measurements in the determination of power and in the revelation of the method of steam-distribution, and Clapeyron * used the same device in his discussion of the newly revealed processes of thermodynamics, as understood in his time. Morin's use of the "stress-strain diagram," now so familiar to all students of the mechanics of engineering and of the characteristics of the materials of construction, makes visible the law of relation of stress to strain, and enables us to detect, easily and with comparative exactness and certainty, the point at which the so-called elastic limit is found, the point at which the strain produced by any applied force becomes mainly permanent, and beyond which every added strain becomes a permanent distortion. Here the stresses are exhibited by the ordinates and the strains by the abscissas, making it easy to devise, as was, perhaps, first done by the writer,† systems of automatic and autographic registration of such curves which give the complete history of such strains as are produced, and of the producing stresses, from the beginning to the end of the process of distortion and fracture; or which, revealing the exact position of the elastic limit, may permit, as was years ago suggested by the writer,‡ the use of a member of any iron or steel structure after a test which determines as certainly as would actual fracture, the reliability of the piece in the place in the structure for which it is made. The electrician and the electrical engineer both employ the "characteristic" curves of electrodynamic machines in their investigations of the adaptability of these machines to their purposes, or of the required adaptations of the motor or the system of application of the current to the exact attainment of the conditions of maximum efficiency in their

* Tait's *History of Thermodynamics*; Thurston's *Translation of Carnot*.

† *Transactions*, Am. S. C. E., "Note on Resistance of Materials," Nov. 19, 1873, vol. ii., p. 290; vol. iii., Feb. 4, 1874; *Ibid.*, 1880, vol. ix., No. cxci., "Materials of Engineering," vol. ii., chap. 10.

‡ *Ibidem*, vol. ii., 1874; *Ibid.*, 1878, "A New Method of Detecting Overstrain, etc."; "Materials of Engineering," vol. ii., chaps. 9 and 10.

use. All these methods of representation of phenomena involve but two variables, and may be made to produce plane curves and may usually be more or less completely covered by equations involving two variables.

The results of a series of observations of such relation between any two variable quantities being entered upon a chart, by careful adjustment to their co-ordinates, the series of points upon the plane, thus obtained, fall naturally as closely into line, and lie as exactly on the curve representative of the law of their relative dimensions, as the skill of the investigator or the accuracy of his instruments may permit. Checking the observations in such manner as to correct errors, as far as practicable, the eye instantly discovers, in the usual case, the trend and location of the curve, and its locus gives the equation; which is the mathematical expression of a law of nature. If, as is often the case, its mathematical form is already known, or deduced from fundamental considerations, the constants become derivable, and the law is determined with precision. Many illustrations occur in papers communicated to technical societies of every kind, and none more beautifully illustrates the method than those of the associations of engineers. Even the engineer's "graphical log" of a steam-boiler trial is an illustration of this most fruitful of processes of representation. In all, a continuous process, guided by natural laws, is traced by a series of discontinuous observations, and these, in turn, being represented by points on a diagram, determine the locus of a curve which is then the exact graphical statement of the resultant effect of the laws thus operating, and is a continuous record of a continuous process.

It often happens that the character of the curve thus to be recorded is known. In such case, the identification of a single point, as the result of a single observation, perhaps, determines the locus of the whole curve. Thus, to-day, by a single steam-engine trial, we may determine the internal wastes of the engine and may lay down a curve by which to exhibit its economical performance over a wide range of conditions, and may even identify that adjustment which is on the whole most economical. The law is known, as is its algebraic representation, and the observation enables us to introduce that constant quantity which locates the path of which the general characteristics and method of curvature are given.

Each observation, in such cases, may also serve to check the accuracy of the whole work. A series of points being established as the outcome of such observations, they will always be found to exhibit some irregularity due to the imperfections of human methods and faculties. But, taking a mean path amongst the points laid down and plotting the curve and, thus detecting and throwing out unreliable observations, we may secure an equation of the true law of variation.

Cases involving three variables may be represented by the institution of three co-ordinates and by referring to them their curves, or by surfaces in three dimensions, and are illustrated by a "Glyptic System," as the writer calls it, which is exhibited best in the various "relief-models" so profitably employed in the topographical work of the geodecist and the state engineer. A glance at the relief-model of the Alps, or the great model of the surface of the North American continent made by the United States Coast Survey, gives a better idea of the topography of the country represented, and permits more satisfactory measurement, than can possibly be secured in any less concrete method of description or representation. Relief-models have been but rarely employed in other departments of engineering work, but an illustration of their potentialities in new fields may be seen in the relief-model employed by the writer to exhibit the variation of the strengths of the alloys of copper, tin and zinc, in their infinite binary and ternary combinations.* As illustrating the system to which it is desired here to call attention, it will not be out of place to give here an engraving and description of this, so far as the writer is aware, earliest of applications of this method to such purposes as are here considered; although this instance is already tolerably familiar to engineers and physicists generally. The problem proposed for solution was the following: †

To determine the useful properties of all the infinite number of possible combinations of the three metals in ternary alloys of copper, zinc, and tin.

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* *Proceedings* American Association for Advancement of Science, 1877, "New Method of Planning Researches, etc."; *Transactions* Am. S. C. E., 1881, No. cxiv., "Materials of Engineering," vol. iii., chap. 11; *Journal*, Franklin Institute, 1884.

† "Report of the United States Board appointed to Test Iron, Steel and other Metals." R. H. Thurston, Secretary, Editor. Washington; Government Printing Office, 1875–8.

The properties of the binary combinations of tin and zinc, and those of the compounds of copper with tin and of copper with zinc presented no special difficulties. Their various proportions and the corresponding moduli of strength and elasticity; their densities, resiliences, liability to liquation and unsoundness when cast, and any other valuable or objectionable qualities, were easily determined in proper sequence and, the results for each series of alloys being plotted, the law of variation of either property with varying composition, and the maximum or minimum for the whole range and infinite variety of composition, could be readily exhibited, or, if unknown, discovered by the inspection of plane curves thus formed. Such results were, in fact, obtained.*

The strongest possible alloy of each pair of elements was thus discovered and announced by the writer, and these researches were fruitful and satisfactory in all ways. It was found that, for the purposes of the constructing engineer, an alloy closely related to "Muntz metal," exhibited the best combination possible of copper and zinc, having the best possible combination of strength, ductility, and elasticity. The best copper-tin alloy, similarly, is very closely allied to gun bronze; while both alloys are strengthened still further—but at the expense in higher degree of their ductility—by the reduction, by a small amount, of their contents of copper, producing, for example, bell and speculum metals in the case of the copper-tin alloys. These facts are illustrated on the relief-model to be now described, and can be seen by studying the contour lines of the two lofty sides of the part richest in copper, which part is seen to contain all the strong alloys.

The principle adopted was the following: †

In any triangle, as at A, Fig. 126, let fall perpendicular supon the three equal sides. The area of the whole triangle B, C, D, is measured by the product of the altitude, CE, by one-half the base, BD. Draw lines, AB, AC, AD, to the vertices of the triangle, thus forming three smaller triangles, the sum of which equals, in area, the original triangle. We now have: $CE \times \frac{1}{2} BD = AF \times \frac{1}{2} BD + AG \times \frac{1}{2} BC + AH \times \frac{1}{2} CD$; or, the sides of the triangle being equal, $CE \times \frac{1}{2} BD = (AF + AG + AH) \frac{1}{2} BD$. Hence, $AF + AG + AH = CE$.

* *Ibidem.* Also "Materials of Engineering," vol. iii., chaps. 9 and 10.

† *Ibidem.*

But the area of the whole triangle may be conceived to represent a ternary alloy composed of the three components in proportions represented by the areas of the three several small

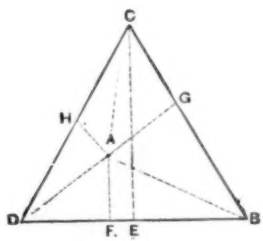


FIG. 126.—TERNARY ALLOYS.

triangles which together make up its total area. But these smaller triangles have areas proportional to their altitudes, *AF*, *AG*, *AH*; the proportions in which the three metals are combined to form the given triple alloy may, therefore, be measured by the ratio of their representative triangles to the whole triangle in area and in altitude. Dividing the height of the large triangle into one hundred equal parts, the altitudes of the small triangles, measured in the same units, will represent the percentages of the three elements in the given alloy.

Every point in the triangle thus represents some certain ternary alloy; there is no possible alloy which has not its representative point in our triangle. We have before us a field which exactly defines our research, and may attempt its exploration with a clear understanding of what is to be done. "Its topography may be studied as systematically and completely as that of any other territory of which the exact boundaries have been determined and marked out."

The results of such an investigation as is finally proposed can now be exhibited by a relief-model, on which the compositions of all ternary alloys can be represented by the location of corresponding points on a base-plane; while the property to be studied as to its method of variation with composition may be represented by ordinates raised upon that plane thus:—(Fig. 127.)

Lay out a triangle, as above described, upon a surface of sheet metal. At selected points at which determinations have been made, erect wires of which the lengths have been made care-

fully proportional to the ordinates of the representative surface at those points, screwing them firmly, or otherwise fixing them, in their places. When all the wires are in place and are found to be of the exact length required, place bits of board along the outside, to form the boundaries of the triangle, and pour in plaster of Paris until the wires are all covered. When the plaster has set, remove the boards and carefully cut away the

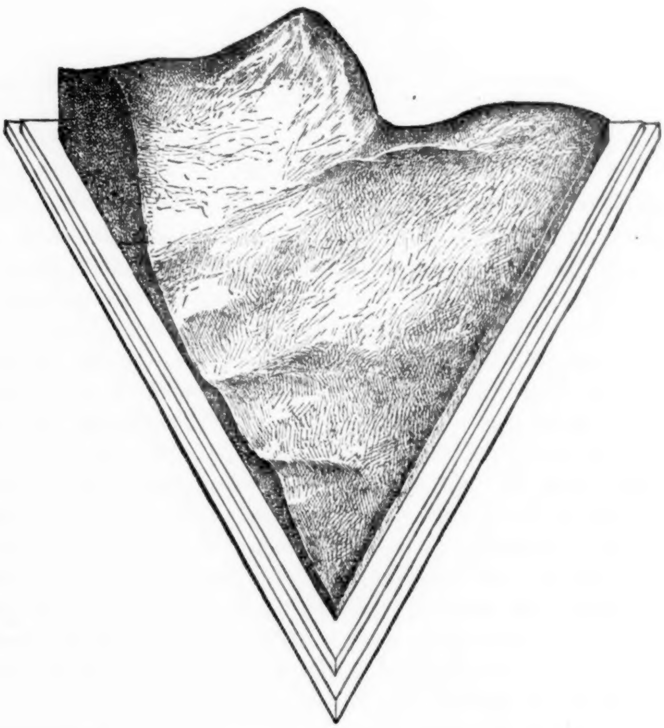


FIG. 127.—A RELIEF-MODEL OF THE "KALCHOIDS."

plaster, working carefully down to the tops of the wires, just exposing their points. The surface thus produced is a model of the strength, or other quality represented, of all these alloys. This can be cast in bronze, or, as in the actual case described here, in the alloy of maximum value, and a handsome, durable, and instructive relief-model thus formed, the maximum ordinate of which discovers the strongest alloy that can be made of the

three elements studied. It was thus that what the writer has called the "maximum alloys" were discovered and fully identified by repeated investigations, among all the infinite possible "kalchoids," or brass-like alloys, obtainable by combining copper, tin and zinc. The strongest copper-tin-zinc alloy exhibits no liquation; its composition being about *Cu* 0.55, *Zn* 0.43, *Sn* 0.2, or neglecting the zinc, substantially that of Muntz metal. The next best alloy was taken as *Cu* 0.55, *Zn* 0.445, *Sn*, 0.005; this having less strength but more ductility, the whole field covered by the range, copper 50 to 60 per cent., zinc 48 to 38 per cent., tin 0 to 0.5 per cent., embraces the most remarkable of these "kalchoids." It includes Tobin's alloy, a chemical combination, having the composition, *Cu* 58.22, *Zn* 39.48, *Sn* 02.30. Repeated investigations with carefully selected and pure metals, using phosphor-tin to insure soundness by perfect fluxing, indentified, as "the strongest of the bronzes," *Cu* 57, *Zn* 42, *Sn* 1; while the substitution of 1 per cent. of copper by 1 of tin, *Cu* 56, *Zn* 42, *Sn* 2. Tin should never, probably, for constructive purposes, exceed 2.5 per cent., and zinc should be kept inside 43 per cent.* This method of investigation thus discovered, as no other method could, the precise character of the whole range of compositions, and revealed, as none other could have done, the existence and the exact location of the alloy of maximum value. The best alloy, thus discovered, if exactly proportioned, well melted, perfectly fluxed, and so formed as to produce sound and pure metallic alloys, with such prompt cooling as shall prevent liquation, is "the strongest bronze that man can make."

It is a close-grained alloy, of rich color, fine surface, and takes a good polish. It oxidizes with difficulty, and the surface then takes on a pleasant shade of statuary bronze green. It has considerable hardness, but moderate ductility, though tough and ductile enough for most purposes; it will forge if handled skillfully and carefully, and not too long or too highly heated; has immense strength, and is well adapted for general use as a working quality of bronze. In composition, it is seen to be a brass, with a small dose of tin. The alloy made for purposes demanding toughness as well as strength contains less tin than the

* Investigation locating the "Strongest of the Bronzes;" *Journal*, Franklin Institute, February, 1883.

above composition: Cu 55, Sn 0.5, Zn 44.5. It has a tenacity of 70,000 pounds per square inch (4,850 kilogrammes per square centimetre) of original section, and 90,000 pounds (6,450 kilogrammes) on fractured area, and elongates 47 to 51 per cent., with a reduction to from 69 to 73 per cent. of its original diameter. This alloy is homogeneous, the fractured surface is in color pinkish-yellow, and dotted with minute crystals of alloy produced by cooling too slowly. The shavings produced by the turning tool curl closely, like those of good iron, and are tough and strong. These alloys, including the "Tobin Alloy," are good working metals, usually being capable of great improvement by skillful working, either hot or cold, and thus of obtaining a tenacity of over 100,000 pounds per square inch (7,311 kilogrammes per square centimetre).* They are generally of a rich golden or reddish yellow color, and make beautiful castings.

The above description of this application of such graphical and glyptic processes will serve to show how readily it permits the solution of important problems and the discovery of otherwise obscure facts, and often in cases which probably no other method would answer such purpose, and especially in the detection of maxima and minima in functions of three variables, among which no mathematical law has been detected and for which we must rely entirely on experiment. In further illustration, it is now proposed to exhibit other hitherto unknown results of previously unpractised applications of this system.

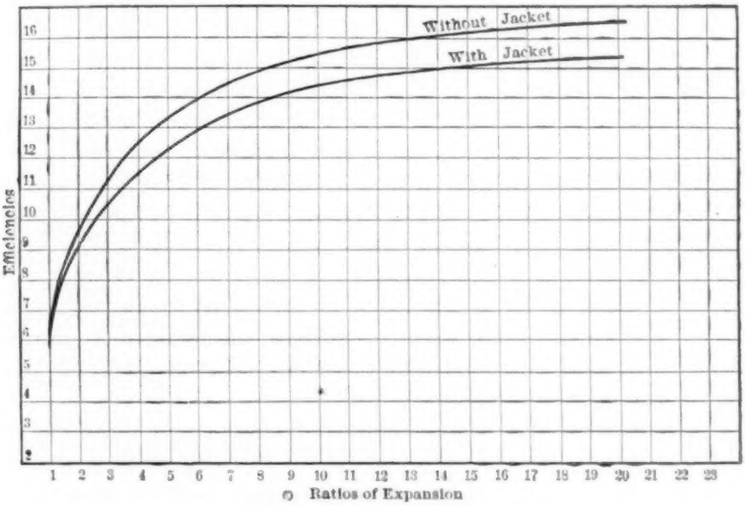
The study of the steam-engine presents many such problems, and Clapeyron, in his utilization of the Watt diagram, and Carnot, long before, in his discussion of the "motive power of heat," the text for the work of Clapeyron, enunciated a number of them.† Two-dimension curves have been hitherto employed only, and only such problems as are capable of solution by plane curves have been usually treated. One of the latest applications of this plan has been that adopted by the writer in exhibiting the method of variation of steam-jacket efficiency in special cases.

It is well-known that the value of the steam-jacket is not due to any inherent economical quality of the jacket itself, but to

* *Ibidem.*

† "Reflections on the Motive Power of Heat." *Translation*, R. H. Thurston. New York: J. Wiley & Sons. 1890.

the fact that, though a wasteful device, intrinsically it has the valuable and economical property of, in many cases, counteracting another and usually greater waste, that by internal transfer of heat without transformation and performance of work. This is easily shown by computing the efficiency of the engine, in the ideal case, no wastes by conduction or radiation occurring, for both the jacketed and the unjacketed engine. The results of such a computation are graphically exhibited in the accompanying curves (Fig. 128), Rankine's assumptions being taken for



EFFICIENCIES OF STEAM IN IDEAL ENGINES.

FIG. 128.

both cases, the steam-pressure being 115 pounds absolute, and expansion ranging from $r = 1$ to $r = 20$, back pressure taken at 4 pounds on the square inch.* It is seen, in this case, that a reduction of efficiency by about 1 per cent., instead of a gain, as commonly noted in practice, follows the use of the jacket. The ideal, unjacketed, condensing-engine gives an efficiency of 12.5 per cent., or 20 pounds of steam per horse-power per hour at $r = 4$, and of 16.5 per cent., or 15 pounds at $r = 20$; while the corresponding figures for the jacketed engine are 11.5 per cent., and 21 pounds and 15.3 per cent., and 16 pounds; and computa-

* *Manual of the Steam-Engine.* Part I., pp. 640. New York: J. Wiley & Sons. 1892.

tions made in this manner will be found invariably to prove that the loss due the jacket increases constantly with rising pressures and with increasing expansion.

The case is quite different with the real engine, in which internal and external wastes occur unavoidably, and often in large quantity. Here, the jacket, by checking these wastes often very greatly, within the engine—though always exaggerating them somewhat externally—gives a net reduction of total wastes, and causes, under favorable circumstances, sensible, and often great, increase of thermal efficiency. This gain is found to have a maximum, probably, as the writer has elsewhere pointed out, somewhere between the values of $r = 1$, at where internal engine-waste is a minimum, and $r = 8$, when jacket-waste is a maximum, and this maximum, for certain cases, is found not far from those ratios of expansion which give maximum economy in the operation of the engine. Thus, the study of the work of the "Research Committee" of the British Institution of Mechanical Engineers enables us to construct curves like that given herewith (Fig. 129), in which the point of maximum effectiveness of jacket is seen to be in all cases identified as to location with great accuracy. The diagram exhibits the action of simple condensing and non-condensing engines, with steam at (1) 110, (2) 90, and (3) 65 pounds pressure.

In the case of the simple non-condensing engine, the use of the jacket reduced the cylinder-wastes from about 25 per cent. of the ideal consumption of steam and feed water to about half that proportion, for ratios of expansion approximating 6; from one-third to about one-tenth, at a ratio of 5; and apparently from 20 to 10 per cent. at 4.4. The jacket gives best results, with 110 pounds of steam, when the ratio of expansion approximates 6. When the steam pressure falls to approximately 80 pounds, the best work of the jacket occurs at a ratio not far from 4.75; while, at the pressure of 50 pounds, the value of the jacket increases through the whole range of the experiments, and not only so, but the curve assumes a rectilinear form, indicative of probable improvement indefinitely in the direction of increasing expansion. The highest efficiencies, however, either with or without the jacket, are found, in this case, at the lowest ratios adopted, and indicate a maximum value at about 3.25. The ratios of expansion for maximum efficiency of fluid, are, for 110 pounds, about 5, and for 80 pounds, about 3.5.

Similarly the condensing engine, for the best work done, whether jacketed or not, is at about a ratio of expansion of 10 (at a steam-pressure of 110 pounds); but the jacketed engine reduces the internal wastes from 50 per cent. at highest ratios, and from one-fourth at the lowest ratios, in the case of the unjacketed engine, to 5 per cent., and in some cases, probably to within the magnitude of the errors of observation. At a pressure of 90 pounds, the best ratio for this engine, under the actual conditions of its operation, is about 6.5 when unjacketed,

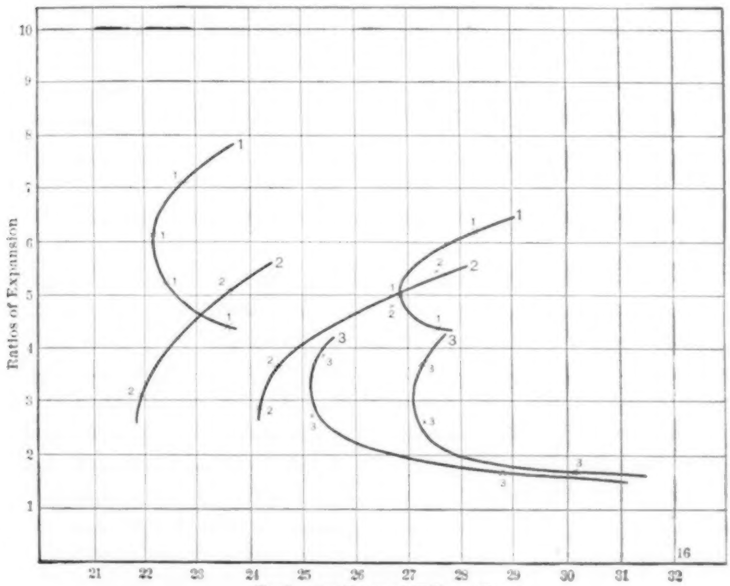


FIG. 129.—SIMPLE ENGINES, STEAM 110, 90, 65 POUNDS.

and 8.5 jacketed, while the lower pressures still further reduce both the efficiencies and the effectiveness of action of the jacket.

The compound engine studied was operated at too low a pressure to bring out the best effect of compounding, but exhibits the same general effects noted in the cases of working of simple engines. The effect of the jacket is less pronounced than in the simple engine, and the efficiencies of fluid vary less with variation of the ratios of expansion. It gives best results at ratios of expansion ranging from 7.5 to 10.5, the variations of the value

being very much more observable in the case in which both jackets are in use, than in either of the others, and least when only the high-pressure jacket was employed. By far the best work was done by the engine when both jackets were in use.

This discovery of a maximum efficiency of jacket may throw some light upon the causes of the conflicting and sometimes apparently irreconcilable results of trials of engines with and without jackets, and with jackets variously constructed. The discovery may also prove of value to the designer, as aiding him in securing the best proportions and arrangement of his engine.* The measure of the value of the jacket may be taken as the ratio of heat supplied, as measured by the weight and cost of water drained out of the jacket, to the gain by reduction of total heat-supply, as measured by the reduction in quantity of heat or of feed water, or of the steam sent to the engine from the boiler, and the cost of the latter. Its economic value increases or diminishes as the excess of gain over loss increases, and in rapid ratio.

Results similar to the above may be obtained by the designer for a proposed engine, by computing the ideal case, adding the expected wastes for a number of adjustments of engine to its work, approximating that anticipated to be on the whole best, constructing curves like those just described as obtained from the actual case, and thus identifying the set of conditions likely to give best results. This is now a familiar method, and need not be further described here.† The results of such computations are illustrated in the next plate, in which the case of a compound engine, worked condensing and non-condensing, is taken and efficiencies of the ideal engine are compared with those of the real engine, steam-pressure 250 pounds, back pressures 5 and 20 pounds, respectively, expansions from 10 to 50 and from 5 to 20. The ideal case is computed by Rankine's methods.‡ The real case is that in which the engine is of such size and proportions as to be subject to wastes in similar proportion to those observed in the Sandy Hook experiments commonly taken by the writer as representative of the performance

* *Manual of the Steam-Engine.* Part I., art. 156, p. 648. Also *Journal* Franklin Institute, April, 1891, "On a Maximum Steam Jacket Efficiency."

† *Manual of the Steam-Engine.* Part I., art. 155, pp. 636–647. Also, *Transactions*, Am. S. M. E., No. ccccli., Vol. xii., 1891.

‡ *Rankine's Prime Movers.* Pp. 375–411.

of engines of 200 or 300 horse-power, for unjacketed simple engines, and three-fourths this proportion when jacketed and one-half the latter quantity when compounded.* The evaporation is taken at 9 pounds water per pound of fuel, for 104° Fahr., for the condensing and 10 from 203° Fahr., for the non-condensing engine.

The plate (Fig. 130) gives not only the computed figures, but the construction of curves, as shown here, with these scattered data determining their loci, and gives beautifully the means of finding maxima and minima—the most important advantage of this system of record by graphic and by glyptic constructions. With data as above stated and assuming an efficiency of machine of 92.5 and of 90 per cent., respectively, for the non-condensing and the condensing engine, the following values can be read from the curves: †

COMPOUND JACKETED ENGINE.

$p_1 = 250$; $p_2 = 5$ and 16; r variable.

CASE.	NON-CONDENSING.		CONDENSING.	
	Ideal.	Real.	Ideal.	Real.
r for Maximum Efficiciency	11	8.5	32	17
" Minimum Fuel	11	8.5	32	17
" " Water	13	9.5	38	21
Water per I. H. P. per hour	12	14.75	8.5	12
Fuel per I. H. P. per hour	1.35	1.68	1 .1	1.55
Water per D. H. P.	13	16	8.5	13.5
Fuel per D. H. P.	1.5	1.8	1.2	1.7

It will be seen that the effect of the introduction of wastes is to reduce greatly the ratio of expansion giving maximum efficiency, and to make variations from that ratio of maximum efficiency more seriously productive of loss, while at the same time making the differences between the several cases less in the real than in the ideal engine. The last given figures for r have no other than speculative interest, as the only important question is at what ratio will the least heat be demanded from the fuel? The better the conditions of construction and operation of the engine, and the less the difference between the two sets of cases, the nearer will the value of the ratio of maximum

* *Manual of the Steam-Engine.* Thurston. Part I., pp. 642–647.

† *Ibidem.* Also, *Transactions*, Am. S. M. E., Vol. xii., 1891, No. ccccxlvii.

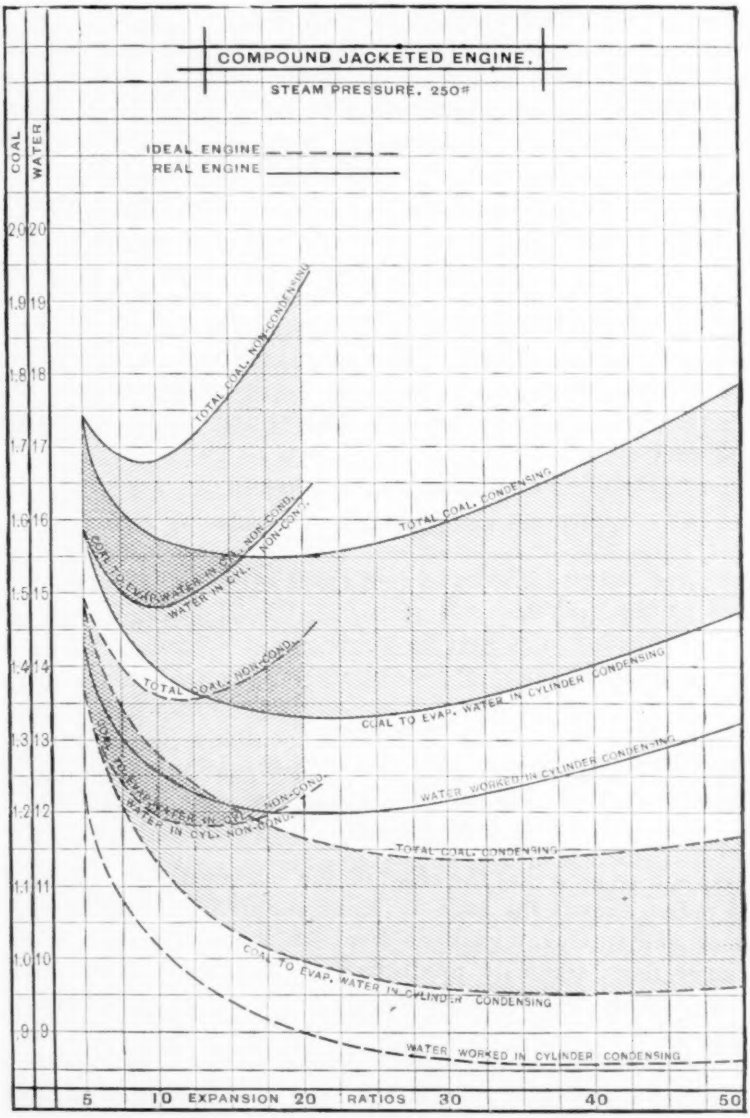


FIG. 130.—STEAM-ENGINE ECONOMY.

efficiency and minimum expenditure of steam and of fuel approach a common value—that for the ideal case.

Mr. H. F. W. Burstall, M.A., has designed an ingenious and convenient model (Fig. 131), exhibiting the relations of pressure,

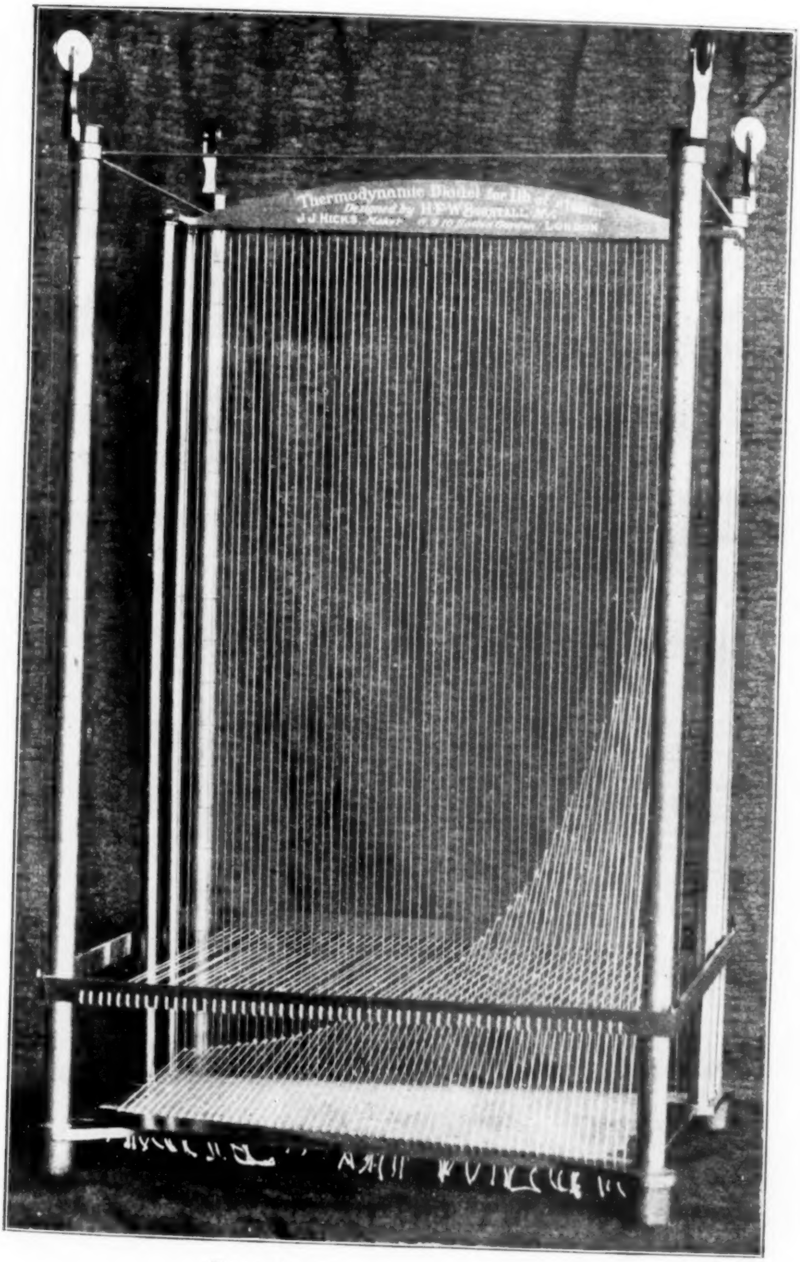


FIG. 131.—THERMODYNAMIC MODEL.

volume and temperature for one pound of steam, in which the various surfaces formed by pairs of co-ordinates are represented by cords and a frame carrying another set of stretched cords is made to traverse the system, constantly parallel with itself, thus giving a plane at any desired point, and identifying the particular set of conditions to be examined, and the values of the defining measures. This very admirable device is shown in the accompanying figure, as made for Sibley College, on the order of the writer, recently, by Mr. Hicks. The moveable frame is counterbalanced, so that it may be readily moved and placed at any desired position. In the figure, it is shown as set a few inches above the base of the model, which is made for one pound of steam. Volumes are measured vertically, as shown by the series of cords of which the uppermost terminals form a parabolic outline as they stretch from the nearer side of the base of the apparatus to the connections with the corresponding vertical cords on the further side. On the base are inscribed scales of temperature and of pressure, absolute, and the volume measures are given upon the corner-posts. The scale at right angles with the temperature-scale is that of entropy. The areas enclosed in the figure marked out upon the base measure entropy-temperature, or heat-energy, in British thermal units.

Prof. W. F. Durand has adopted a very interesting glyptic system of representation of the thermodynamic properties of steam, the model for which is seen in Fig. 132. This gives a continuous, glyptic, history of the mutual relations between the three characteristic quantities of the substance, pressure, volume and temperature, and for H_2O in every state from that of a mixture of steam and water, through the definite stage, saturated steam, to the condition of superheated steam. The co-ordinates measuring pressure and volume are here taken in the horizontal plane and temperature in the vertical direction.

The surface exhibiting the p, v, t relations of steam and water is cylindrical, its section being uniform in planes parallel to p. t, and its axis lying in the direction of the axis of volume. Its equation is :

$$p = f(t) \text{ ; or } t = \omega(p),$$

which function is that expressing the relations between pressure and temperature for saturated steam.

For saturated steam, the locus is a line on the cylinder above described, which is defined by a value of v equal, at each

value of p or t, to the volume of unity of weight of saturated steam under these conditions.

The superheated-steam figure is taken as represented by the equation

$$p v = 85.5 \ T,$$
$$p v = 0.5937 \ T,$$

the one or the other of these expressions being adopted, accord-

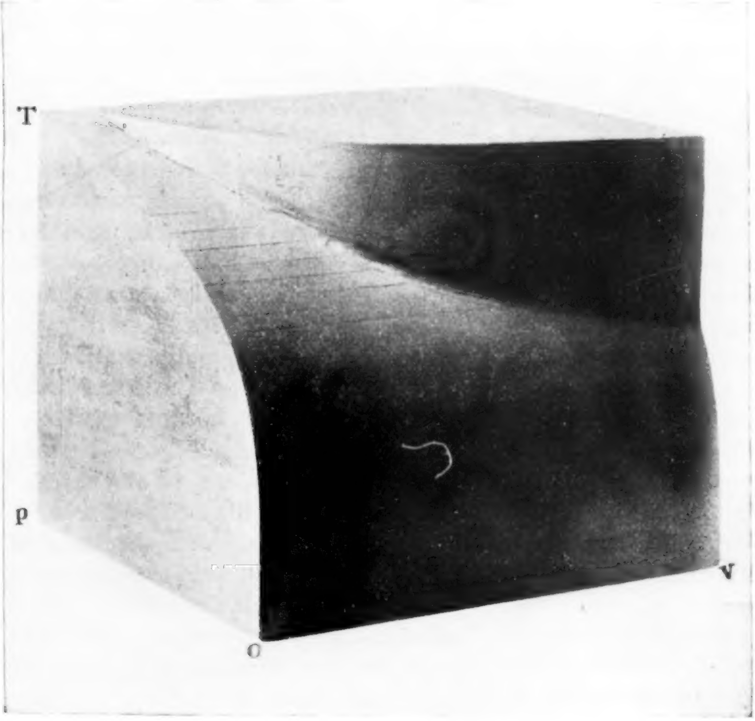


FIG. 132.—STEAM GENERATION MODEL.

ingly as the pressure is measured in pounds on the square foot or in pounds on the square inch.

The two surfaces illustrated on the model for the two cases above described do not intersect each other sharply and with the production of a defined angle; but, as the intermediate condition is approached, gradually become blended, in accordance with the well-known experimentally determined facts of the case. Neither the one or the other of the two surfaces exactly

represents the condition of the fluid as shown by experiment to exist when the substance is changing from the saturated to the superheated condition; and it is also the fact that the higher the temperatures and pressures, the broader the space marking the transition period. At low temperatures and pressures, as we near the freezing point, saturated vapor is considered a gas by Rankine and other writers, a condition which can only be attained at high-pressures by considerably superheating it. Thus, between the two main surfaces lies an intermediate portion, constituting a fillet of insensible dimensions at low pressures and becoming very observable at high pressures, where the superheating must be made some 15 degrees or more to produce gasification.

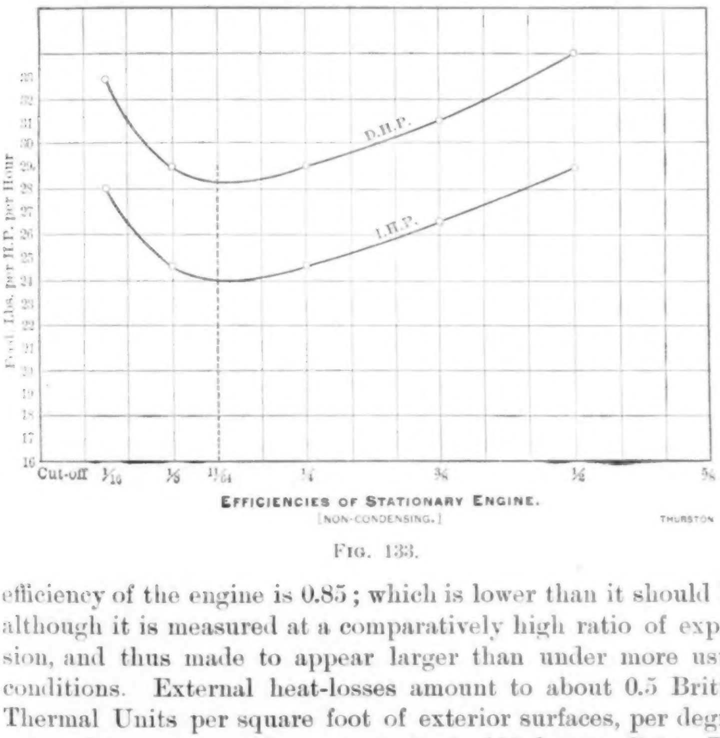
The model here shown is constructed for temperatures up to 360 degrees Fahr., for pressures up to 153 pounds per square inch, and for volumes limited to 22 cubic feet. The units employed are, in this example, those of the Fahrenheit scale of temperature, volumes in cubic feet, and pounds on the square inch.

Horizontal sections on this model give the isothermal curves for the whole range, from the condition of water, through the various proportions of water and steam, up to the condition of superheated steam at the limit of the scale adopted. Vertical sections, parallel to $p\ t$, give continuous histories of the relation between pressures and temperatures for constant volume. Vertical sections, parallel to $v\ t$, give continuous measures of the relation between volume and temperature at constant pressure.

Adiabatic lines are space-curves, here running obliquely downward toward increasing volume, and those of appropriate location cross the intermediate condition, from the one surface to the other, illustrating the fact first brought out by Rankine and by Clausius, of condensation of dry or superheated steam with adiabatic expansion.

The accompanying diagram, Fig. 133, represents the varying efficiencies of an "automatic" steam-engine, making 280 revolutions per minute, and with an ordinarily good steam-distribution, the constants in the equations of the curves employed having been determined by a careful trial of the engine, and thus made practically exact for such an engine. The fact of the existence of a well-defined point of maximum economy of heat

and steam and fuel is well brought out by the diagram. The table which follows shows what variations may be expected as consequent upon varying steam-pressures, and further shows clearly, though not with precision, the existence of a similar point of maximum economy for every pressure, which point, however, is found at a higher ratio of expansion as pressures rise, as is in any case obvious. In the formula for computation of internal wastes of heat and steam, a is in this instance very nearly 4, as in the Sandy Hook experiments.* The mechanical



EFFICIENCIES OF STATIONARY ENGINE.
[NON-CONDENSING.]
THURSTON

FIG. 133.

efficiency of the engine is 0.85; which is lower than it should be, although it is measured at a comparatively high ratio of expansion, and thus made to appear larger than under more usual conditions. External heat-losses amount to about 0.5 British Thermal Units per square foot of exterior surfaces, per degree range of temperature above atmospheric, 100 degrees Fahr. The engine is non-condensing and demands about $W = 250/\sqrt{p}$, pounds of steam per indicated horse-power per hour, at best cut-offs. The best ratio of expansion is not far from $r = 0.5\sqrt{p_1}$. For best commercial results, about two-thirds this ratio is usually better.

* *Manual of the Steam Engine*, vol. i., art. 137, *et seq.* $W = a \ d \cdot \sqrt{rn}$; d = diameter cylinder; r = ratio expansion; n = revolutions per second.

EFFICIENCIES OF NON-CONDENSING ENGINES.*—[R. H. THURSTON.]

r	Cut-off.	Pressure, Pounds per sq. in. (absolute).	Terminal Pressure, Pounds per sq. in.	Terminal Pressure, Pounds per sq. ft.	Indicated Power.	Steam per I. H. P. per hour (Ideal), W.	Internal Waste Coëffic, $W = \frac{a}{d}\sqrt{\frac{r}{n}}$	Internal Waste, Pounds per I. H. P. and per hour.	External Waste, Pounds per I. H. P. and per hour.	Total Waste, Pounds per I. H. P. and per hour.	Total Consumption, pounds per I. H. P. and per hour.	Same per D. H. P.
16	$\frac{1}{16}$	75	3.22	463.7	3.100	*15.85*	1.234	19.56	3.30	22.86	38.71	45.54
8	$\frac{1}{8}$	75	7.08	1,020	6.42	*15.32*	.87287	13.37	1.50	14.93	*30.25*	*35.58*
4	$\frac{1}{4}$	75	15.55	2,239	11.77	*16.72*	.61720	10.32	.847	11.167	27.887	32.80
2.7	$\frac{3}{8}$	75	24.29	3,498	14.97	*18.48*	.50710	9.88	.666	10.546	*30.026*	*35.32*
2	$\frac{1}{2}$	75	34.15	4,918	17.85	*21.44*	.43650	9.71	.555	10.265	*32.51*	*38.24*
1.6	$\frac{5}{8}$	75	44.00	6,336	19.90	*24.76*	.3900	9.66	.502	10.162	*34.92*	*41.08*
16	$\frac{1}{16}$	95	4.08	588	4.83	*12.74*	1.234	15.73	1.663	17.393	30.133	35.45
8	$\frac{1}{8}$	95	8.97	1,292	9.31	*13.21*	.87287	11.53	.969	12.499	*25.71*	*30.24*
4	$\frac{1}{4}$	95	19.70	2,837	15.97	*15.42*	.61720	9.09	.966	9.656	25.076	29.50
2.7	$\frac{3}{8}$	95	30.77	4,431	20.58	*17.72*	.50710	8.99	.428	9.418	*27.14*	*31.93*
2	$\frac{1}{2}$	95	43.26	6,229	24.20	*20.34*	.43650	8.88	.375	9.255	*29.595*	*34.81*
1.6	$\frac{5}{8}$	95	55.72	8,024	26.62	*23.11*	.3900	9.02	.333	9.353	*32.46*	*38.19*
16	$\frac{1}{16}$	115	4.94	711.8	6.18	*11.91*	1.234	14.70	1.360	16.060	27.97	32.91
8	$\frac{1}{8}$	115	10.86	1,564	11.62	*12.68*	.87287	11.07	.755	11.825	24.55	28.82
4	$\frac{1}{4}$	115	23.84	3,433	19.68	*14.97*	.61720	9.24	.415	9.655	*26.48*	*28.97*
2.7	$\frac{3}{8}$	115	37.25	5,364	25.28	*17.35*	.50710	8.80	.331	9.131	*28.836*	*31.15*
2	$\frac{1}{2}$	115	52.36	7,540	29.64	*19.88*	.43650	8.68	.276	8.956	*30.00*	*33.92*
1.6	$\frac{5}{8}$	115	67.46	9,714	32.60	*22.60*	.3900	8.82	.251	9.071	31.67	*37.26*
16	$\frac{1}{16}$	135	5.8	835.6	7.534	*11.38*	1.234	14.05	1.043	15.093	26.473	31.14
8	$\frac{1}{8}$	135	12.75	1,836	13.91	*12.32*	.87287	10.75	.504	11.314	23.63	27.80
4	$\frac{1}{4}$	135	27.99	4,031	23.37	*14.67*	.61720	9.05	.344	9.394	*24.06*	*28.30*
2.7	$\frac{3}{8}$	135	43.73	6,297	30.00	*16.96*	.50710	8.60	.263	8.863	*25.82*	*30.37*
2	$\frac{1}{2}$	135	61.47	8,852	35.00	*19.54*	.43650	8.53	.216	8.756	*28.29*	*33.28*
1.6	$\frac{5}{8}$	135	79.19	11,403	38.50	*22.25*	.3900	8.68	.208	8.888	*31.13*	*36.62*
16	$\frac{1}{16}$	155	6.66	959.4	8.89	*10.98*	1.234	13.55	.836	14.336	*25.36*	28.84
8	$\frac{1}{8}$	155	14.63	2,106	16.20	*12.05*	.87287	10.52	.462	10.982	27.03	27.09
4	$\frac{1}{4}$	155	32.14	4,628	27.00	*14.41*	.61720	8.89	.274	9.164	*23.57*	*27.73*
2.7	$\frac{3}{8}$	155	50.2	7,223	34.58	*16.72*	.50710	8.48	.213	8.693	*25.41*	*29.89*
2	$\frac{1}{2}$	155	70.58	10,163	40.50	*19.28*	.43650	8.41	.182	8.592	*27.87*	*32.74*
1.6	$\frac{5}{8}$	155	90.92	13,092	44.48	*21.95*	.3900	8.57	.164	8.344	*30.68*	*36.26*

* For details of computations of such results, see Thurston's *Manual of the Steam Engine*, vol. ii. and App., edition of 1897.

Maxima and minima of functions of three variables, as has been seen already, may be found as readily by the use of glyptic or relief representation as can those of two variables by the use of plane curves; and the whole area of investigation may be thus explored to find special, or peculiarly interesting or important results. The following application of the method first employed by the writer to the determination of compositions of

maximum value, among the kalchoid alloys, illustrates an original investigation of efficiencies of the steam-engine by similar processes, as made under supervision of the writer, and completed by the construction of bronze relief-models, photographs of which will give some idea, at least, of the broad and fruitful character of these methods. All the computations were made by Messrs. H. W. Ludlam and E. R. Hill, in the laboratories of Sibley College, during the college year 1891–2. The models were constructed by Mr. Hill mainly, the curves and plaster casts serving as models for the metal reliefs, having been made as the work of computation progressed. All figures were checked by double computation and comparison.

An engine worked at its minimum limit of economical steam-pressure as was assumed, was selected for study and test. This machine had the dimensions:

Cylinder diameter, inches	21.0
Piston stroke, inches	20.0
Clearance, per cent	9.5
Indicated horse-power	125.5
Boiler pressure, pounds	100.0
Vacuum, inches	24.0

Initial condensation is found to amount to 41 per cent., a large proportion, but not remarkable for an unjacketed cylinder. In fact, little could be expected of a jacket here, if used. The expansion of the steam, as shown by the diagrams, follows very closely the law taken as correct for steam dry and saturated, and the index $n = 1.132$. This index is taken as $n = 1.035 + 0.1\,x$; when x is the "quality" of the steam—in this case 0.966. Had this line been exactly followed, without loss due internal waste of heat between cylinder and condenser, the indicated horse-power would have measured 168, instead of as actually, 125.5. The co-efficient for this case is here, therefore, $125.5/168 = 0.74$.

Taking the case as representing the expansion of one cubic foot of steam from the initial pressure, we find, by the exact formulas of thermodynamic transformations occurring adiabatically and between 100 and 7 pounds per square inch, absolute, the ratio of expansion, r; and the terminal volume, v, is 11.28 cubic feet. By the approximate expression, $pv^{1.132}$ = constant, the figure is 11.31. The volume of the fluid measured off, as steam, per stroke, was 0.425 cubic feet; strokes per minute, 166; computed horse-power, 168; actual as measured, 125.5.

Studying this case the problem was attacked; to determine the best expansions and best pressures for this engine under different loads. In the solution of this problem, three variables entered, and the glyptic system of representation is therefore illustrated. In the surface thus constructed, the points of cut-off are laid off on the axis of X; the pressures on the axis of Y, and the weights of water demanded, per horse-power and per hour, are given by the ordinates on Z. Then curves of constant load may be drawn and projected upon the surface; and curves of equal water-consumption similarly. This being done, the power demanded, during a given run, being known or estimated, the eye, at a glance, sees what is the best pressure and cut-off for that load. Pressures are here taken ranging from 190 to 90 pounds, absolute, and ratios of expansion from 16.67 to 0.1; "cut-offs" varying between 0.06 and 0.23, as referred to the large cylinder. As representing a general case, the Rankine approximate expression for adiabatic expansion of moist steam was used in the computations: $pv^{\frac{10}{9}}$ = constant, A, constant difference above given, was taken between the ideal and the actual diagram, and between the computed and the probable real work done. Internal wastes were computed by the Fourier formula, giving an error on the right side, and probably unimportant.* Curves of condensation-wastes were drawn for each pressure, and the values, x of this loss, thus obtained were employed in finding the total consumption of water by adding the fraction of condensation thus obtained to the computed quantity of steam demanded in adiabatic expansion. That is to say $(1 + X)$: multiplied by the steamed computed or measured for the ideal case was taken as the probable steam consumption.

The accompanying plate exhibits graphically these variations of waste, for four pressures and for a wide range of expansion-ratios, and exhibits the general fact of rapid exaggeration of wastes by increasing expansions, and the increase of wastes of this character with increasing pressures and ranges of temperature between initial and terminal and back pressure. (Fig. 134.)

The plate illustrates the variation of water consumption per horse-power per hour, the same premises being taken, and the well-known fact of the existence of a minimum at a ratio of expansion appropriate to each pressure for the given engine.

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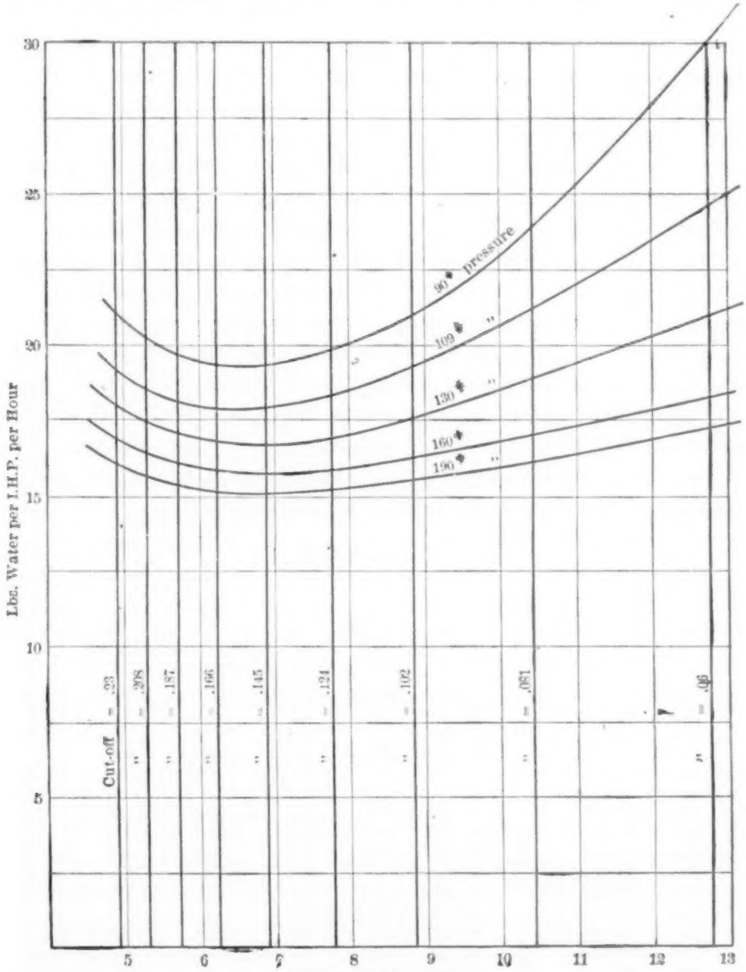
* *Manual*, page 517.

Thus we find the best ratio of expansion in this respect for this engine, in this case, at about 7, varying from 6, nearly, at the lowest of these pressures to a trifle over 7 at the highest. It is also



ENGINE EFFICIENCY.

FIG. 134.

seen that, in these cases, the economical expansion is less subject to variation of serious amount with varying loads at the highest than at the lowest pressures, the water-consumption varying much less in the latter cases. The engine is not only

more economical at the highest pressures, but has a more constant efficiency.

The table next given presents the final results of all computations so far as needed for the production of the models to be here used in illustration of this paper. These figures are now to be employed in the construction of curves forming elements of the surface to be constructed in the solution of this problem. The figures thus obtained being transferred, on a convenient scale, as shown in the next plate, it is easy to make them a basis for such a method of operation and such a construction as was employed, first, in the exhibition of the useful qualities of the alloys. The several lines of water-consumption for constant ratio of expansion and varying pressures, as shown, herewith, in Fig. 134 above, being drawn, each is taken as the intersection of an appropriate plane with the surface to be constructed; and these several elements being found and their ordinates erected on the base-plane, the construction of the required relief model becomes a simple and easy matter. The surface taken as illustrative, in this case, was formed by direct transfer of the lines here shown, in reduced scale.

STEAM-ENGINE EFFICIENCY.

r	p	U Computed.	U	U Per Diagram.	P Ideal.	P Real.	Water Per Hour Indicated.	Water Per Hour. Actual.	Water per hour per I. H. P. Actual.
5	90	26,600	.874 − .102 = .772	20.520	206.8	174	3.215	3,376	19 39
	109	33,240		25,650	259	226	3,850	4.042	17.9
	130	40,700		31 400	317	284	4,545	4.772	16.82
	160	51,150		39.400	398	365	5.530	5,806	15.9
	190	61,750		47,700	481	448	6,500	6,825	15.25
6	90	27,800	.728 − .102 = .626	17,380	175	142	2,604	2,747	19.35
	109	34,900		21,820	220	187	3,120	3,354	17.9
	130	42,800		26,800	270	237	3,685	3,965	16.72
	160	53,800		33,650	340	307	4,480	4.834	15.72
	190	65,500		41,000	413	380	5,275	5,723	15.08
9	90	29,020	.485 + .102 = .383	11,100	113	80	1,590	1,828.5	22.85
	109	37.100		14,160	143	110	1,908	2,261	20.6
	130	46,000		17,600	177.5	144.5	2,250	2,670	18.48
	160	58,650		22.450	226.5	193.5	2,740	3,258	16.8
	190	71,500		27,360	276	243	3,220	3,896	16.05
12	90	29,020	.364 − .102 = .262	7,600	76.7	43.7	1,089	1,340	30.7
	109	37,600		9,820	99.25	66	1,300	1,638	24.8
	130	47,240		12,380	125	92	1,538	1,940	21.1
	160	60,950		15,950	161	128	1,870	2,356	18.35
	190	74,750		19,580	197	165	2,201	2,863	17.35

The model, as finally produced and cast in bronze for class-illustration, is shown in the Fig. 135, reproduced by photographs from the original. This surface now gives the results of all possible adjustments of pressure and cut-off within the extremes chosen for its field; and we see here, as in the case of the ternary alloy model, that we are thus enabled to represent an infinite number of cases from the results of study of a few, and to find a minimum or a maximum, if it exists, whether it happens to be one of the cases selected or not; the chances being, of course, infinitely against such an occurrence. We see at once, also, that there is no maximum efficiency within this range, for this engine, with increasing pressures; but that there are maxima with varying ratio of expansion.

The variation of the pressures from lowest to highest, over a range of 100 pounds per square inch from the lowest taken as suitable for the engine studied—between 90 and 190 pounds—produces a wide variation of economical working for each cut-off, but there is a general tendency to increase efficiency with increasing pressures, whatever the expansion; and this variation also tends to approach a common minimum expenditure of heat, steam and fuel, at about 1,000 pounds, probably, but quite off the field explored, and beyond the range of current practice, or even of radical practice of the present day. The consumption of water and steam is seen to vary with rough approximation, as the reciprocal of the square root of the boiler pressure, and to be represented, for usual conditions, as a minimum, by

$$w = a \div \sqrt{p_1};$$

where a varies from about 250 in the least favorable case given, to 185 for the best. Perhaps 200 may be taken as fair value, here. It is evident that, under the conditions here assumed, it is advisable to adopt as high a boiler pressure as may be found by experience wise on the score of prudence, and desirable on the score of insurance. This conclusion is supported by the fact that we are constantly increasing pressures, in locations in which economy of fuel is seriously important, as at sea, and that no thermodynamic limit is yet in sight.

The variation of the ratio of expansion, or of cut-off, illustrates a very different law. It is seen that the model represents a portion of a valley between elevations, and that it shows plainly and indisputably the now familiar fact of the existence of a

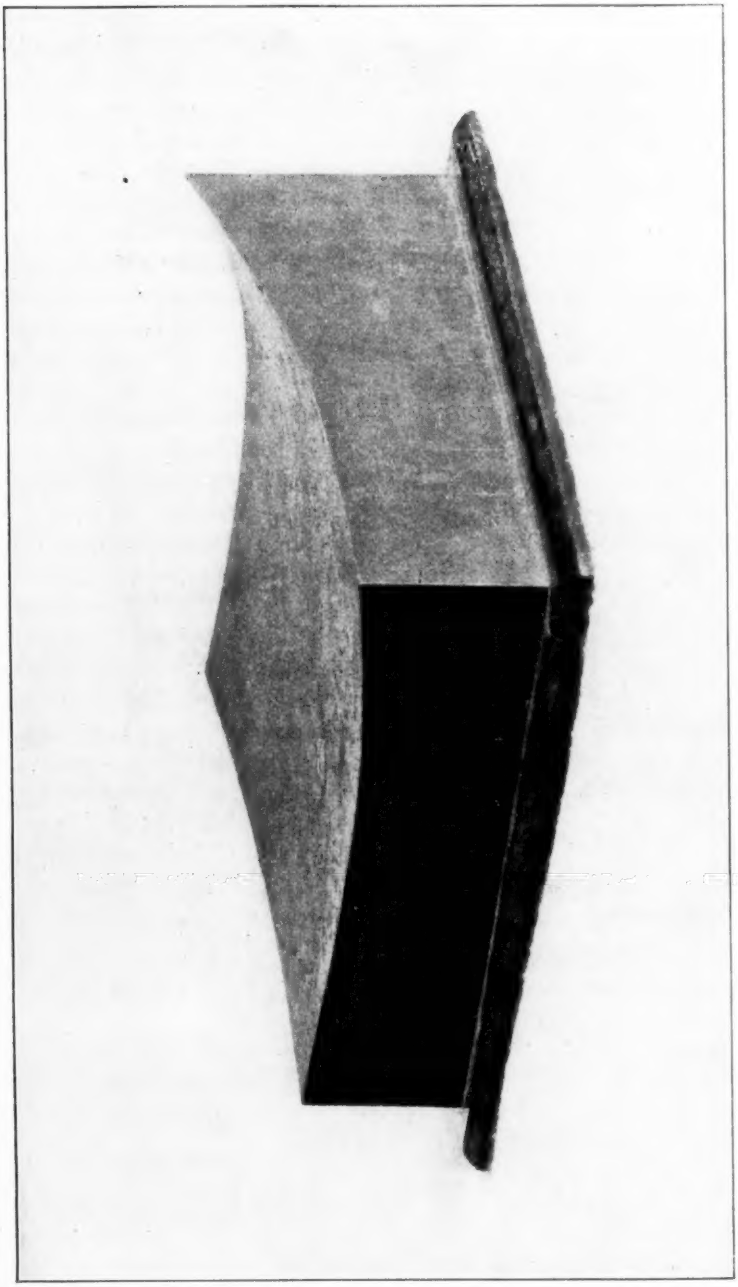


Fig. 135.—Relief-Model of Engine Efficiencies.

minimum economical expansion, a maximum efficiency with varying cut-off, as shown by Isherwood, experimentally, for the marine engine a generation ago (1860).* This expansion for maximum efficiency is seen to be substantially the same for all pressures, with the engine here studied, and under the conditions assumed as those of its operation and is very nearly $r = 7$, thus corresponding accurately with the deduction of Hallauer for the compound engine, as the result of his comparatively limited experimental researches. A singular deduction, such as this, could be given positive proof by such a concurrence of evidence only as could be secured either by a very large number of observations, or by the construction of the surface in which scattered observations could be grouped and made to sustain each other by falling into a smooth area of which the intersections by vertical planes, in whatever directions, give smooth curves. It is only by such constructions that the point of maximum efficiency for both pressure and expansion can be identified with accuracy at all, or a fact like that just pointed out discovered. It is this conclusion that is here intended especially to be emphasized, and the precise value, or even the exact precision of the illustrative example is here of no special importance. The value of the method can be now readily recognized and fully appreciated. The result of this particular observation is the determination of the fact that, assuming the premises to accord with current and average fair practice, we may anticipate a gain in economy by increasing steam pressures in similar cases without known limit, and an economy in water-consumption varying about as the reciprocal of the square root of the boiler pressure. It is thus indicated that the deduced ratio of expansion represents a cut-off of maximum efficiency, the cost of operation, in fuel and in steam, being greater with either a larger or a smaller ratio of expansion. It is further seen that, under such conditions of operation, the variation in efficiency with varying pressures is less rapid as this best adjustment is approximated, and that, with varying cut-off, the differences are greater as the pressures are lower, while becoming comparatively small with the highest pressures. A drop of water would trace, by its flow on this model, a line of minima and of best adjustments for the whole series of pressures. High pressures

* Experimental Researches in Steam Engineering.

are thus less subject to wastes from variable loads with this engine than are low pressures. If we were to apply it to electric street railway work we should adopt the highest pressures practicable. The premises here taken are, in the opinion of the writer, fairly representative of good average practice, and these deductions are probably fairly accurate for the cases taken.

Still another, and perhaps even a more important, and certainly more curious and interesting problem may be solved, and has been solved, for this engine by this system of glyptic representation. This problem bears the same relation to the Rankine problem of the best point of cut-off, as a problem in finance, that the problems of maxima and minima in the differential calculus bear to those solved by the application of the calculus of variations. As already seen, the graphic representation of a series of observations by means of a curve, as in the case of the binary alloys and of the curves of water-consumption which have been described, permits the identification of the exact location of a minimum or of a maximum, even though that point may be not even approximate to any computed or observed point identified for the curve. Similarly, the employment of the glyptic system of representation of variations of three quantities, as here illustrated, in the relief-model of the ternary alloys, and in these engine-efficiency surfaces, affords a means of determining accurately the curve of best result in any given case of variation of either pair of variables, and also the maximum or the minimum in that curve, and for the whole surface. It may even happen that there are two or more such curves or such minima or maxima.

The final problem, in the present case, is the following: *To find the best adjustment of power for the given engine, and the best arrangement of pressures and expansions for that load.*

The following case is presented as illustrative of the method, not as giving a specific set of values. These should be determined for each case, and by reference to the commercial conditions of that particular case and for the circumstances characteristic of the location and operation of the machine. We proceed thus:

Construct a surface which the ordinates, z, represent the work done per unit weight of water, or unit volume of steam, consumed, the abscissas on the axis of x the cut-off, and those along y the varying steam-pressures. This surface will be found quite simi-

lar to that already illustrated, but inverted—ordinates here being reciprocal of those—and being convex instead of concave to the base-plane. (Fig. 136.) Let the work performed by the engine at any given pressure and cut-off be represented by the effective horse-power of the machine—its dynamometric power—determined either directly by experiment for a suitable set of observations as to number and distribution, or by computation of selected cases, giving uniformly distributed ordinates. Horizontal, x z, planes passed through the surface thus constructed will, by their intersections, give a set of curves of equal power and work, like the profile lines on a topographical relief. The figure here given illustrates such a surface and such lines as obtained for the case in hand. This surface intersects the base-plane at some distance from the origin, its ordinates becoming negative at that line representing those values of the power and work at which the internal and other wastes become so great as to consume all steam supplied, and just turn the engine over at its prescribed speed, without external load at its shaft or on the dynamometer. Vertical planes passed through this surface, parallel to the axis of x, form by their intersections "curves of efficiency," as the writer has called them, such as Rankine first described for the ideal case, and such as, for the actual case, the writer has applied to the solution of similar problems relating to the real engine, all wastes being taken into account.* The present problem requires the identification, first of the best of these curves for the given engine and for a stated power, and second the best adjustment of pressure and cut-off for that power and pressure, financial considerations being the controlling conditions. Once this surface is obtained for the proposed engine and for a sufficiently wide range of conditions, the solution of this problem involves simply the examination of the market prices for the locality in which it is to be used, and the questions proposed for solution are quickly and easily answered. In many cases these quantities are not ascertainable with perfect accuracy; but they may almost invariably be determined with sufficient approximation for practical purposes, and even an approximate solution of such problems is vastly better than the usual "guess" of the builder, who invariably seeks maximum duty and usually gives altogether too large an engine for highest commercial efficiency.†

* *Manual of the Steam Engine*. Part i., chap. 7. † *Ibidem*.

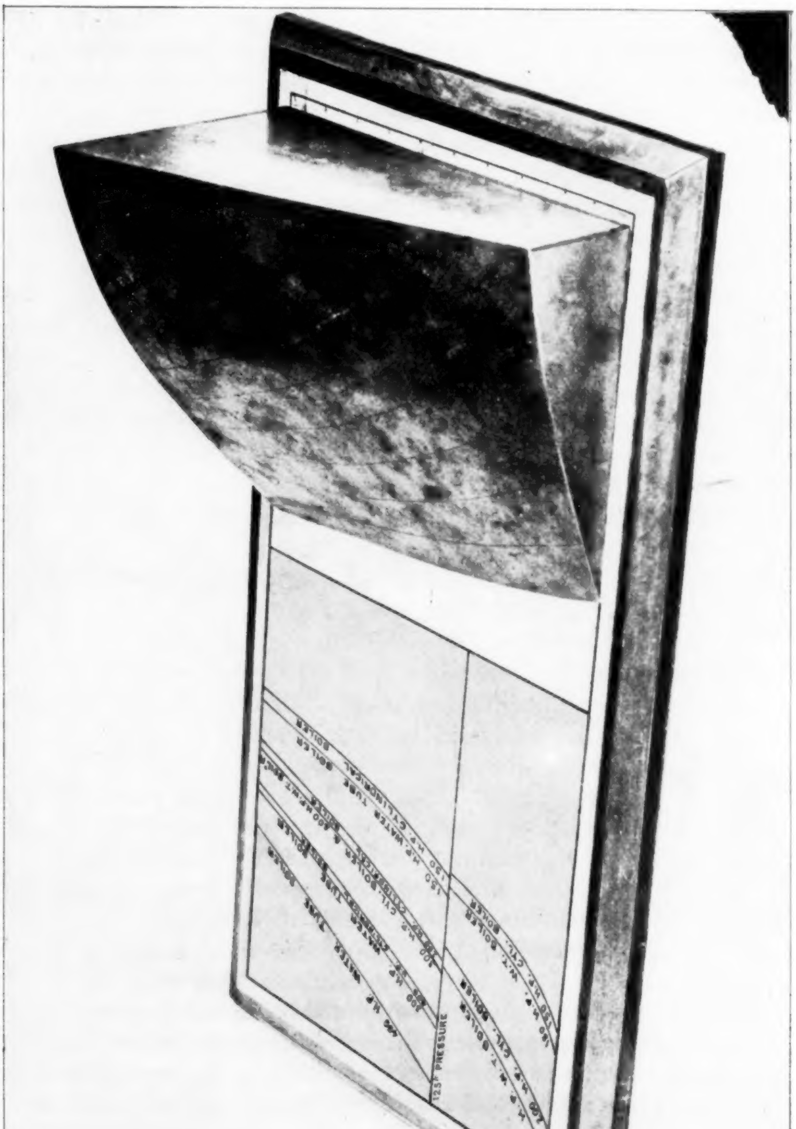


FIG. 136.—COMMERCIAL EFFICIENCIES.

Such a model being constructed, many problems may be solved readily and with satisfactory accuracy which could, perhaps, not be solved at all, or, if at all, only with great difficulty, and with indifferent accuracy and certainty, by any other means. This new application of the relief-model thus serves an excellent purpose in the prosecution of those investigations which have now come to be of primary importance in the further advance of our practice in steam engineering. Since the ordinates in y measure the work done by quantities of steam measured on the abscissas in x, for any given steam pressure measured off on z, the unit of measure may be taken as required, either with reference to the work performed at full stroke, as unity, which was Rankine's method, or with reference to the power of the given engine taken at full stroke, as unity. If we take the horse-power of the engine as indicated by the various curves on the surface of the model by intersections with suitably located horizontal planes, the ordinates will measure the quantities of steam required to do those quantities of work referred to that needed for full-stroke performance as a standard.

Since the ordinates, on my appropriate scale, thus measure work and the abscissas in x the corresponding expenditure of steam, we may take the latter as the measure, also, of the costs of that steam, costs at full stroke being the unit. This permits the application of the construction to the solution of all problems of maxima and minima within its field, relating to costs and commercial efficiencies.* The ratio of cost of steam to work done by it is measured by the ratio of ordinate to x-abscissas, for any point on the surface, and this ratio is a maximum when the angle made by the secant drawn from the point to the origin makes the largest possible angle with the axis of x; and this occurs when it becomes a tangent to the surface. Hence, to find maxima, we have simply to draw from the origin lines tangent to the surface, in any $x\ y$ plane, taken, as desired, on such point in z as represents the proposed steam-pressure, and the expansion for maximum duty at that pressure and for the given engine is obtained. This, in turn, identifies the best power at which to rate the engine, on this basis. Further, if we measure off, to the left, along x, distances proportional to the costs of operation which vary proportionally with the size of

* *Ibidem*, Art. 181.

engine, and measured in units of value equivalent to the cost of the steam used for full-stroke of the engine of unity volume for full-stroke work, we find what proportion the costs variable with the size of engine bear to the similar costs of steam variable with size of boiler, unity volume of steam being, in this case, taken as demanded at full-stroke. These costs may be two or four per cent., for example, of the full-steam costs. Adding to the abscissas, by drawing in at the left of the origin this proportion of the total steam-costs, similar maxima to those previously found may be obtained which will show what is the best method of working steam, the best expansion and the best size of engine for economical operation, from the financial point of view. Numerous other problems may be solved in a similar manner.* The identification of the test pressure and expansion for a given power, with a given engine, is one of those problems which illustrates the value of the surface representation, the "surface of efficiency," as distinguished from the "curve of efficiency." Finding the plane giving the maxima efficiency, and that point in its curve of intersection with the surface which gives maximum efficiency in that plane, the best adjustment of engine to its work is revealed, and a problem in the calculus of variations is thus given a constructive solution with the greatest ease.

Thus, in the present case, the model gives us the stated data for the case in which the problem proposed is to find the adjustment of an extremely wasteful engine at various pressures from 90 to 190 pounds, to insure highest duty, as measured by the ratio of dynamometeric work to weight of steam and fuel required to perform it.

These cases are simply illustrative, and are not to be taken as more than fairly approximative in any one problem, and then only for the engine and for the conditions of operation there taken as found by test of the engine, and by investigation of markets at its proposed location; but they exhibit the fact that the real problem of economy in engine-operation dictates, as a rule, much smaller engines, and lower thermodynamic efficiency than is commonly sought for, and less, much less, than can be obtained with the engine adjusted for maximum duty, irrespective of its own running costs and the treasurer's account of

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* *Ibidem*, Arts. 193–7.

annual expenses, including the value of capital invested in it and its accessories.

It will be noted that all the ratings here obtained, as exhibited above, give ratios of expansion far within those usually considered to dictate the adoption of even the compound engine; and it follows that the designer, for the case here taken would employ a simple engine, presumably taking the precaution to insure dry or moderately superheated steam, and, if the engine is to work at low-speed, or if it has proportions justifying it, jacketing its cylinders. It happens that in this particular case the multiple-cylinder engine would not pay, and it is not impossible that it might actually prove to be less economical than the simple engine. This, at first thought, singular result of the investigation comes of the fact that the engine selected for study is of small power and large proportional area of cylinder-wall, and seriously subject to internal and other thermal wastes; such as would not usually occur in any such proportion in a more powerful or better designed or larger engine. The larger the engine the dryer the steam, and the more perfectly it is protected against internal and external wastes, the larger will be the ratio of expansion at which it can be ecomically adjusted to work, and the more nearly will it approximate in its commercially satisfactory operation those conditions which are known to distinguish the ideal case.

Thus, for example, the figures for a good condensing engine, for steam-consumption per horse-power per hour may approximate the quantity, $W = \frac{25}{\log p}$, a limit now actually overpassed, while an ordinarily well-designed, but small, engine may demand fifty per cent. more, and the common small engine on the market double that quantity of feed-water for each indicated horse-power. The terminal pressure, for maximum duty, in the best cases, falls as low as 7 or 8 pounds, absolute, with condensation, and 20 pounds on the square inch, above vacuum, with non-conducting engines, while, with more wasteful machinery, it may rise to double these figures. The high-pressure element of the Sibley College Experimental Engine, were the model constructed to represent that case, would give the following, as already reported: *

* *Transactions*, Am. S. M. E., Dec., 1866, vol. xviii.

Economics of Ideal and of Real Engine (9 In. × 36 In.; 86 Revs.)
Constant Quantities.

Boiler-pressure, by gauge	100 lbs.
Revolutions per minute	86 "
Quality of steam at engine, per cent	98 "
Back pressure, pounds per square inch	5 "
Friction of engine, horse-power	7.25 "

Expenditure in pounds of steam per horse-power per hour.

Ratio of Expansion.	Ideal Engine.	Frictional Loss.	Radiation.	Initial Condensation.	Real Engine.	
					Per Model.	Total Observed.
1	32.91	1.73	.267	7.62	42.63	......
2	20.50	1.75	.268	6.68	29.18	29.10
3	16.70	1.78	.268	6.70	25.45	24 6
4	15.11	1.80	.270	7.01	24.19	23.1
5	14.21	1.83	.271	7.40	23.71	*22.8*
6	13.52	1.86	.272	7.70	23.35	*22.6*
8	12.67	1.98	.275	8.27	*22.20*	23.7
10	12.22	2.12	.280	9.10	24.08	24.0
12	11.90	2.37	.291	9.50	24.06	24.5
15	11.70	2.71	.305	10.30	24.92	25.5
20	11.61	3.06	.331	12.00	27.00	28 0

The minimum expenditure would be found at six or eight expansions, and seven would be presumably selected on this basis. The finance of the case would probably bring it down to five. The triple-expansion engine, under similar conditions, gives highest duty $r = 13.8$, and demands 13.3 pounds of feed-water, 14,000 British thermal units per horse-power per hour. Its best commercial performance, with coal at $4 per ton, and usual costs for other supplies and attendance, will be not far from 16 pounds at a ratio of expansion of about 8. The limitation of the expansion-ratio in the manner thus indicates a limit to the introduction of the multiple-expansion engines, where fuel is cheap and labor expensive and repairs a serious item, and, from this point of view, as shown so strikingly by these glyptic representations of the relations of conditions affecting ultimate economy, it is readily seen that every engine should be proportioned with direct and final reference to the influence of its operation upon the dividend-paying power of the establishment of which it forms a part. In addition to the wastes, thermal and dynamic, here brought into prominence by their serious influence upon the best steam-distribution of the engine, it is found that business considerations are no less imperative in their dictation of

proper adjustment of the engine to its work and in directing that compromise between the conflicting conditions which will give the best satisfaction from the standpoint of the stockholder.

A model, such as is here described, might thus be made to give a complete representation of the whole field of practice in steam-engine construction, and the proper apportionment of the machine to its work under specified conditions characterizing any one market. Thus, in the table, we have such determination for a variety of steam-pressures, and for a variety of types of engine. The ratio of initial and back-pressures; the ratio of expansion, r', for maximum efficiency of fluid or maximum indicated power for a stated amount of heat, steam or fuel employed; the ratio of expansion, r'', for maximum efficiency of engine, giving lowest steam-consumption for a stated power delivered and for highest duty; the ratio of expansion at maximum commercial efficiency, r''', the highest efficiency of the money expenditure, all these are easily determined, the correct data being once secured and properly used. In the table, the assumption is made in obtaining the last mentioned datum, that fuel costs five dollars per ton, and the ratio, M, of costs of the engines considered as an investment to the costs of the steam supplied, both measured by the unit of volume, is as given in its appropriate column in each class.*

RATIOS OF EXPANSION AT MAXIMUM EFFICIENCY OF FLUID, OF ENGINE AND OF CAPITAL.

Simple Engines.—Dry Steam. *Compound, Condensing, Jacketed.*

ABSOLUTE INITIAL PRESSURES.	NON-CONDENSING, HIGH SPEED.					CONDENSING, MODERATE SPEED.					DRY AND SATURATED STEAM.					SLIGHTLY SUPERHEATED STEAM.				
P	M	$\frac{P_1}{P_b}$	r	r^{ii}	r^{iii}	M	$\frac{P_1}{P_b}$	r^{i}	r^{ii}	r^{iii}	M	$\frac{P_1}{P_b}$	r^{i}	r^{ii}	r^{iii}	M	$\frac{P_1}{P_b}$	r^{i}	r^{ii}	r^{iii}
40	.02	2	2	2	2	.04	8	2½	2¼	2	.04	7	6	5	3	.05	8	8	6	5
60	.02	3	3	3	2¾	.04	12	3½	3¼	3	.04	11	8	7	4½	.05	12	11	8	6
80	.02	4	4	3¾	3¼	.04	16	4¼	4	3½	.04	14	9	8	6	.05	13	14	10	7
100	.02	5	5	4½	3½	.04	20	4¾	4½	4	.04	17	10	9	7	.05	18	16	12	8
120	.02	6	6	5½	4	.04	24	5½	5	4½	.04	20	11	10	8	.05	22	20	15	9
150	.02	7½	7	6	4½	.04	30	6	5¼	5	.04	25	13	10	9	.05	27	25	17	10

* *Manual Steam-Engine*, vol. i., chap. 7. *Transaction*, Am. S. M. E., 1882, *et seq.*

The revelations of otherwise unobservable or unnoticed phenomena, and especially the easy identification of maximum or minimum values of important data by the use of these graphic and glyptic methods, are seen to be, sometimes, at least, of great interest and occasionally of supreme importance. The examples here are given to be taken merely as illustrative, for they are based upon data which are only correct for the special cases to which they are applied; but it is usually easy to ascertain, with entire accuracy and certainty, all the quantities needed to insure as exact deductions for any case with which the engineer has to do and thus to effect entirely satisfactory application to everyday practice.

The fact that it is now well-established that we may often, if not commonly, by a single engine-trial, determine the constants needed to make application of the equations of the various curves of these diagrams, and to construct these models, furnishes a new and powerful means of analysis to the designer and builder. The form of each line is known by its general equation, and the experimentally determined constant locates the line. With form and location given, the numerical value of not only the co-ordinates of the point of maximum or minimum becomes known, but also the relations of adjacent values and the method of variation with varying working conditions.

It is probable that innumerable applications, and many new methods will be discovered or devised, once such processes of investigation and research come into general use.

DCCLXXIV.*

MECHANICAL PROPERTIES OF CERTAIN ALUMINIUM ALLOYS.

BY R. C. CARPENTER, ITHACA, N. Y.

(Member of the Society.)

THE investigation of the mechanical properties of the various alloys of aluminium and other metals has been in progress for the past five or six years in the laboratories of Sibley College, Cornell University. The results have not in many respects proved as satisfactory as desired, and the writer feels that the investigation has served to bring out information regarding methods and mixtures which should not be employed, rather than to give much positive knowledge of desirable alloys. In fact, the difficulties which have been brought to light have prevented the complete and full investigation which was laid down in the original scheme.

For these various reasons the paper is to be considered only as presenting certain isolated facts, rather than as describing a complete investigation of all the fields which relate to the alloys in question. Investigations are still in progress, and it was not intended to publish the present paper until a later meeting, but Captain Alfred E. Hunt of Pittsburg, believing that the investigation had served to point out a few alloys of commercial value, and also because of the location of the spring meeting, desired the presentation of such facts as had been definitely determined without waiting for the completion of the entire investigation, which doubtless will require considerable time. It is hoped that data may be forthcoming from other experimenters and practical engineers which will supplement or correct, or supply omissions in that given in the paper.

The general method of investigation involved in every case, first, the manufacture of the alloys, which was done by adding the various component parts in accordance with a predetermined

* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

scheme. Second, a mechanical test of the alloys, which was generally made as extensive as the conditions would permit. These tests generally involved the ordinary tests for strength, but were in some cases considerably curtailed on account of the nature and amount of the alloy.

An investigation was made in the case of several of the alloys to find the relation, by chemical analysis, between the various ingredients in the product and those added in the process of manufacture. The result of that investigation indicated that if the alloys were properly mixed, the proportion of the various metals, especially the aluminium, as shown by the chemical analysis, should not differ by more than one per cent. from the amount added in manufacture. The mixtures in which the aluminium varied more than this were rare, and generally due to improper methods used in manufacture. The impurity of the metals used in the mixtures always caused a slight and unexpected variation in the results, since the purest metals which could be purchased contained from $\frac{1}{2}$ to 1 per cent. of impurities. This fact renders the proportions of the mixtures, even in spite of the utmost care, to a certain extent approximate. It is believed, however, that careful mixing will produce alloys with like properties when metals of from 98 to 99 per cent. pure are employed. In nearly every case the results with the better alloys have been checked by making entirely separate mixtures of the metals independent from those first made, and in no case have the properties of the second mixture been essentially different.

The aluminium which was employed for this purpose was furnished by the Pittsburg Reduction Cómpany, and was of a grade guaranteed to be over 99 per cent. pure. The other metals were obtained of various dealers in metals, using, however, precautions to obtain those of the highest grade and with a known standard of purity.

Alloys of aluminium and copper and of aluminium and tin had been investigated by other observers before the commencement of the investigations recorded here, and mixtures of these metals were tested only to a limited extent.

Aluminium, Tin, and Copper Alloys.

The special investigation of these alloys was conducted under the writer's direction by two graduate students, Mr. G. T. Geb-

hardt and O. P. Ward, in 1896. In making the investigation it was determined, in order to limit the number of experiments, to take a fixed percentage of one metal, as, for instance, aluminium, and add to this equal amounts of the other two, which method also had the incidental advantage of permitting a graphical illustration of the behavior of the alloys without the use of three co ordinate planes.

Preliminary test pieces for tension tests were first made with the Al., Sn., and Cu., varying respectively, by increments of 20, from 20 to 100; *e. g.*, 20 Al., 40 Sn., and 40 Cu.; 40 Al., 30 Sn., 30 Cu., etc.

Great care was taken in making these specimens so as to eliminate all errors and to insure uniformity of conditions. New graphite crucibles were used; the mixture was thoroughly stirred before being poured, and the molten metal was not permitted to become superheated; the copper was invariably melted first, and the Al. and Sn. added by degrees. The specimens were all cast in green sand under a 6-inch sprue-head, and were allowed to chill in the mould. These preliminary specimens were not turned in the lathe, and they were tested without the use of extensometers. The results of this test are shown in column A, Table I.

These preliminary test pieces were remelted, and carefully turned in a lathe to a uniform diameter. They were tested with the use of the extensometers, and the results are given in column B, Table I.

Torsion pieces were then cast from these broken test pieces, and, after having been carefully machined to standard size, were tested in the Thurston autographic machine. The result of this test, with that of a few scattering alloys, is given in Table II. The results of this entire test were plotted with ordinates as indicated.

Specific Gravity.

The specific gravity follows a definite law, varying with the composition, and decreasing with the addition of aluminium. The plotted curves accompanying the report show the variation for various mixtures.

Difference between Composition by Mixture and by Analysis (Chemical).

Several specimens were chosen at random from the lot and

analyzed. In each case there was a small variation from the original mixture. Specimens from the second and third remelting were also analyzed, but the variation was but slight.

Separation of the Metals.

In several of the bars, especially those high in tin, a considerable amount of liquation took place. The amount of this separation depended upon the rapidity with which the specimen was chilled, *e. g.*, the bar containing 80 per cent. of Sn. and 10 per cent. each of Al. and Cu., when allowed to cool in the mould, showed this liquation in a remarkable manner; the three metals had separated into three distinct layers, the heavier metal being on the bottom; however, when suddenly chilled by being thrown into cold water, no separation whatever took place, the alloy being closely grained and perfectly homogeneous.

Strength.

The bars containing from 85 to 95 per cent. copper have considerable strength, are close-grained, and of a beautiful golden color; their machined surfaces do not tarnish on exposure to the air. In the copper end of the series, the dividing line between the strong and the brittle alloys is precisely that at which the color changes from a golden yellow to a silver white, viz., at a composition containing between 78 and 80 per cent. copper.* At the elastic limit, the torsional strength is closely proportional to the tensile strength. Alloys of these three metals, compounded of simple multiples of their atomic weights, are very soft and spongy, and have very little strength. Considerable liquation takes place in them. However, there seems to be some definite law by which the strength decreases from the maximum to a minimum, which has no relation to the atomic weights, but to the percentage of composition only. In the aluminium end of the series the strength rises from that of pure aluminium to a maximum at about 90 per

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* For a similar observation of this relation of the colored to the white and gray alloys, in the case of those of Cu., Sb., and Zn., see "The Materials of Engineering," vol. iii. §§ 246-266, pp. 414-451, Thurston. Also report by same author, to U. S. Board, on "The Strongest of the Bronzes;" Washington, Government Press, 1878-81.

cent. Al.; from here it gradually decreases to a minimum at 30 per cent. Al. In the tin end of the series a similar change takes place, as can be seen by referring to the plotted curves of their strength. The alloys containing from 78 to 20 per cent. copper (inclusive) are very hard and exceedingly brittle, and are practically worthless for purposes where strength is required; they could not be machined, as large chips would fly off in advance of the tool, and in some instances the whole test piece would fall to pieces by the jar of the lathe. Specimens containing between 70 and 40 per cent. tin were very soft, the tin in most specimens crystallizing out in large, coarse crystals. Their melting points are extremely low, and, as a consequence of the great length of time that it takes for them to chill in the mould, considerable liquation takes place. The bars contain between 60 and 40 per cent. Al., are very porous and spongy, and are more of a mechanical mixture than alloy.

In the scattering alloys, 10 Al., 1 Sn., and 89 Cu. formed a tough, closely grained, highly colored alloy of considerable strength and medium ductility. 12 Al., 2 Sn., and 86 Cu., and 13 Al., 2 Sn., and 85 Cu. were very strong, coarse grained, and rather brittle. The curve is precisely the same in nature as that for cast iron, breaking without a distinct elastic limit. The alloys are about as hard as cast iron, and take a beautiful polish, which does not tarnish.

The following tables and curves show in detail the strengths, etc., of these various alloys.

The diagram (Fig. 137) shows the strength of the various alloys by the ordinates and the composition of that element of which a fixed percentage was added by the abscissa, the other two being in each case equal to 100 per cent., minus the percentage added. Thus, in the line marked copper, the strength is shown by the numerical values of the ordinates marked on the scale to the left, and the percentage of copper by the numbers denoting the abscissa; the percentage of aluminium or of tin would each be equal to one-half the difference between 100 and the percentage of copper. In the same way, the curve marked aluminium shows by its ordinates the strength, and by the abscissa the percentage, of aluminium present, that of copper and tin being in equal amounts, and found by subtracting the percentage of aluminium from 100, and dividing by 2.

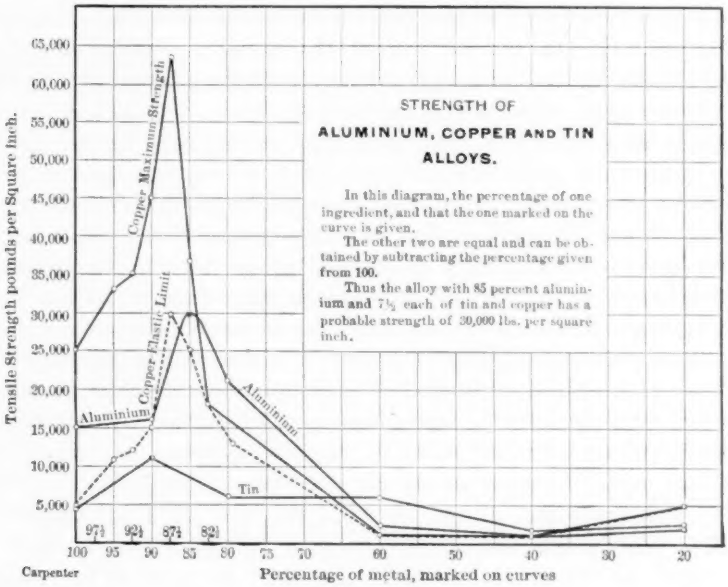

FIG. 137.

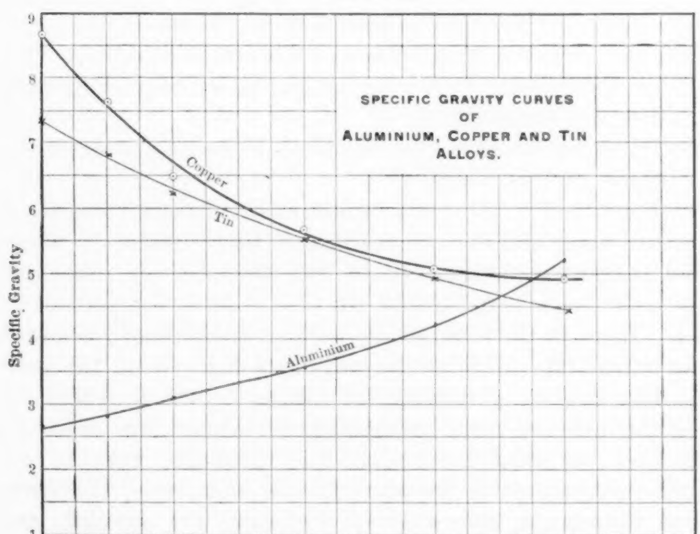

FIG. 138.

In the curves of specific gravity (Fig. 138) the scale at the left gives the specific gravity, the figures at the bottom the composition, by the same plan as used in Fig. 137.

A series of curves plotted with ordinates of three dimensions would have shown somewhat better variations of the character, of that, in a metal made of three ingredients than a curve of two dimensions; but on attempting to plot such a curve, it was found that there were so many combinations still unexamined that the curve selected seemed, on the whole, to show the results more clearly.

The important alloys in the aluminium-copper-tin series are given in the following table, which is taken from the results of the investigation, and is as follows:

ALLOYS OF MAXIMUM STRENGTH.

Percentage of Aluminium.	Percentage of Copper.	Tin.	Strength per sq. in.	Specific Gravity.	Elongation per ct.
85	7.5	7.5	30,000	3.02	4.0
6.25	87.5	6.25	63,000	7.35	3.8
5	5	90	11,000	6.82	10.1

It will be noted, from the character of the investigation, that all possible combinations of these three metals are not examined; and it is, of course, not certain but that stronger metals would be found by combining all three ingredients in unequal proportions; the time, however, required for a complete examination of this kind has not as yet been possible to obtain.

Alloys of Aluminium and Zinc.

The alloys of aluminium and zinc were made in essentially the same manner as those of aluminium, tin, and zinc, by W. F. Hunt and W. J. Andrews in 1894. The results of this investigation serve to prove that aluminium and zinc alloy very readily, and that proportions consisting of from 60 to 70 per cent. aluminium make sound castings, having low melting points and a strength not greatly different from that of brass.

A study of the curve of strengths (Fig. 139) shows that the alloy consisting of two parts of aluminium and one part zinc

TABLE I.

Aluminium Alloys.—Tensile Strength.

Composition per Cent. by Weight.			Ultimate Strength Lbs. per Sq. In.		Tensile Strength at Elastic Limit Lbs. per Sq. In.	Specific Gravity.	Elongation per Cent. in 6 Inches.
Al.	Tn.	Cu.	A.	B.			Per Cent.
......	......	100	27,000	28,330	12,000	6.5	6.5
5	5	90	40,815	42,038	13,832	7.6	4.0
10	10	80	32,209	34,200	24,829	6.5	0.8
20	20	60	1,966	2,225	*	5.7	....
20	30	40	849	1,077	*	5.05	....
40	40	20	4,800	5,672	*	4.91	....
100	......	......	15,000	14,316	6,432	2.67	5.62
90	5	5	15,476	17,070	8,227	2.82	3
80	10	10	18,580	21,140	13,329	3.09	1.2
60	20	20	4,416	5,950	*	3.53	.3
40	30	30	915	1,123	*	4.4	....
20	40	40	2,221	2,622	*	5.21	....
......	100	......	3,505	3,933	....	7.3	35.51
5	90	5	11,582	10,418	4,823	6.77	10.15
10	80	10	5,999	5,922	2,988	6.24	1.1
20	60	20	1,198	1,200	*	5.55	....
30	40	30	993	961	*	4.96	....
40	20	40	3,798	3,997	*	4.48	....

A. Results of first melting. B. Results of second melting.
Test pieces 6 in. between shoulders, diam. ½ inch.
* Could not be turned in the lathe.

TABLE II.

Aluminium Alloys—Torsional Strentgh.

Composition per Cent. by Weight.			Angle of Torsion Deg.		Shearing Stress per Sq. In.		General Character.
Al.	Tn.	Cu.	Elastic Limit.	Maximum.	Elastic Limit.	Maximum.	
......	......	100	2	130	4,300	25,000	
3.5	2.5	95	4	200	10,710	33,075	Very soft ; ductile.
5.75	3.75	92.5	6	198	11,827	35,802	Soft ; ductile.
	5	90	7	175	15,525	45,155	Slightly tough ; ductile.
6.25	6.25	87.5	4	37	30,282	63,440	Tough ; medium ductility.
7.5	7.5	85	3.5	22	25,447	37,062	Very tough ; rather hard.
8.75	8.75	82.5	7	10	18,413	18,413	Hard ; somewhat brittle.
10	10	80	6	8	15,230	15,230	Very hard ; brittle.
*11	11	78	5.8	5.8	13,717	13,717	" " exceedingly brittle.
*20	20	60	1	1	2,321	2,321	" " " "
				Scattering.			
2	10	88	3	147.5	14,000	43,987	Somewhat soft ; ductile.
10	1	89	5	52	21,740	50,000	Tough ; medium ductility.
12	2	86	9	9	32,984	32,984	Very tough ; hard.
13	2	85	8	12	32,723	37,003	" " "
85	7.5	7.5	3	37	8,703	17,630	Very soft ; somewhat ductile.
27.1	119	69.6	2.5	20	2,800	2,800	" " spongy.
100	......	......	2	160	4,005	12,911	

* Could not be machined.

is the strongest in the series. The excellent property of this alloy for practical purposes was first noted by Professor W. Durand, in 1896, who, desiring a metal which would make very sound and strong castings for model work, made experiments with the best metal of the aluminium-zinc compounds, as shown

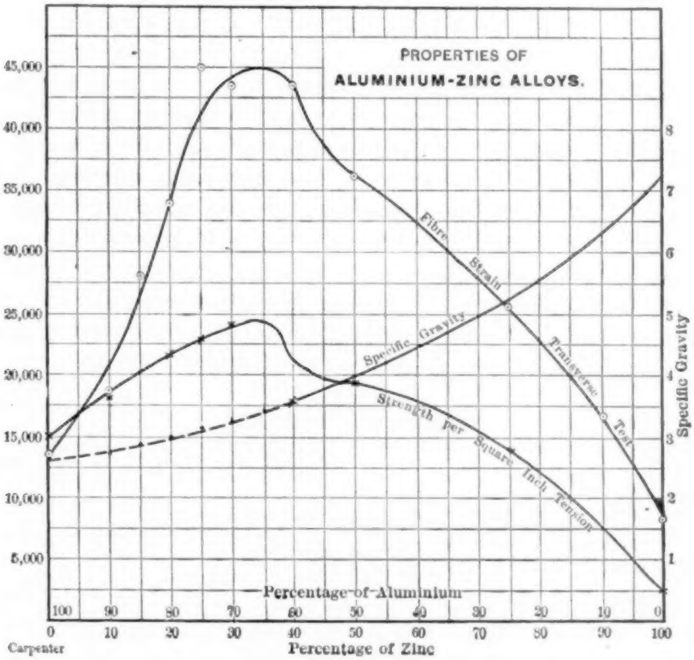

FIG. 139.

by the experiments. This metal has proved so satisfactory for such purposes that for the past two years it has been used extensively as a substitute for brass castings in almost all the work in the laboratories of Sibley College. Professor Durand has proposed for this alloy the name of "Alzinc," which seems to the writer very appropriate, since it indicates the principal ingredients.

The practical use of this metal has proved that it is susceptible of a high polish,* that it does not tarnish in the air, that it is readily worked with lathe or planer tools. In working it, the

* See remark in discussion of this paper.

tools should be rather sharp, and ground about the same as for cutting steel. The chips hold together with considerable tenacity, so that it is possible to remove chips of great length. The tensile strength of this material is 24,000 to 26,000 pounds per square inch, or fully equal to the best cast iron. It is a very rigid material, and possesses, like most all the aluminium alloys, very little ductility. In the opinion of the writer it will serve as a substitute for cast brass in nearly every position where cast brass is serviceable; it will not, however, serve as a substitute for the soft or leaded brasses, since it possesses little ductility. It seems especially well fitted for valve bodies and other similar uses, and for such purpose it is believed that it can be manufactured cheaper than brass, as because of its superior lightness, even with present prices in metals, its cost is not essentially different from that of brass at twelve cents per pound. Recent investigations indicate that this alloy becomes quite ductile at a temperature of 400 degrees Fahr., and at that temperature may be rolled or drawn.

TESTS OF ALUMINIUM-ZINC.

Percentage.		Specific Gravity.	Tensile Strength. Pounds per Sq. Inch.	Transverse Strength. Maximum Fiber Stress. Pounds per Sq. Inch.	Modulus of Elasticity.	Remarks.
Aluminium.	Zinc.					
100	0	2.67	14,460	14,500	6,535,000	Uneven shrinkage.
100	0	2.67	16,750	14,150	....	" "
90	10	2.77	17,940	18,950	7,710,000	
90	10	2.74	....	....	....	
85	15	2.918	....	28,090	9,260,000	
85	15	2.918	18,100	....	....	Shrinkage uneven.
80	20	2.998	21,850	....	9,110,000	" "
80	20	2.975	....	34,600	....	" "
75	25	3.15	22,940	....	8,210,000	" "
75	25	3.14	....	45,080	....	" "
70	30	3.191	24,400	43,200	8,178,000	Shrinkage even.
70	30	3.24	23,950	41,200	....	
66$_{3}$	33$\frac{1}{3}$	....	....	....	....	
65	35	3.326	....	....	....	Poor specimen.
60	40	3.471	....	....	....	
60	40	3.57	19,770	40,350	8,540,000	
50	50	.....	19,300	38,100	....	
50	50	.....	19,060	39,850	8,500,000	
25	75	.....	13,175	25,500	....	
25	75	.....	14,150	....	8,670,000	
0	100	7.19	2,522	7,556	6,680,000	Elongation of all the specimens less than 1 per cent.

Alloys of Aluminium and Cast Iron.

Practical tests of alloys of aluminium and cast iron were made by W. J. Keep of Detroit, and reported in the *Transactions of the American Society of Mining Engineers*, vol. xviii. The results of Mr. Keep's investigations indicate that the addition of aluminium had little or no beneficial effect on the iron, except possibly in some conditions to make it flow freer in the moulds.

The investigation recorded here was made by Mr. E. M. Doyle, a graduate student. It was found as a result of this investigation that aluminium would alloy readily with cast iron up to an amount of 14 to 15 per cent. by weight, and produce alloys having considerable strength; but for mixtures with greater percentage of aluminium the alloys were granular, and possessed practically no coherence.

The general results indicated a falling off in tensile and transverse strength, and also in power to resist impact in proportion as the percentage of aluminium was increased; or, in other words, the effect of the aluminium was to weaken the cast iron, and also to make it brittle.

The results of the various tests are best shown by the accompanying curves, which in each case give the percentage of aluminium added to the iron as abscissa, and the results of the various tests as ordinates. It will be noticed that considerable variation was found in individual specimens, which was due, to a great extent, to imperfect castings and mechanical difficulties connected with the production of the alloys. The line drawn through the diagrams indicates as well as can be predicted the average strength due to the various mixtures in Figs 140, 141, and 142.

Magnetic Properties of Aluminium-Iron Alloy.

Some tests were made in 1891 by C. Eickemeyer, and recorded in the *Sibley Journal* for that year, for determining the magnetic properties of alloys of aluminium and cast iron. The alloys tested contained respectively $\frac{1}{8}$ and $\frac{1}{2}$ per cent.

The determination showed no marked difference in the conductive power of aluminium iron and ordinary cast iron, but there was a small difference in favor of the iron with the smallest portion of aluminium, thus leading to the general conclusion that the addition of aluminium to cast iron does not improve its conductive powers.

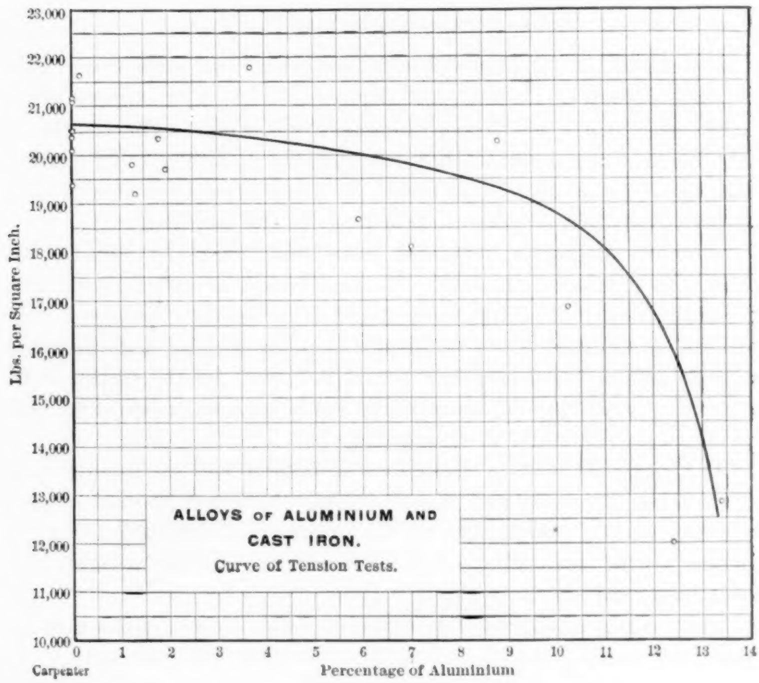

Fig. 140.

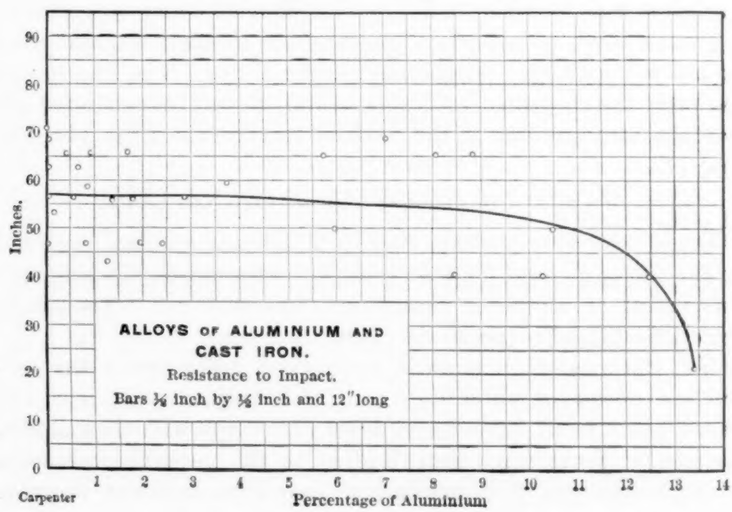

Fig. 141.

Alloys of Aluminium and Magnesium.

Tests were made in 1893 of a number of aluminium-magnesium alloys by L. S. Marks and S. A. Barraclough, graduate students. It was thought that a valuable alloy might be found from the general similarity and properties of the two metals.

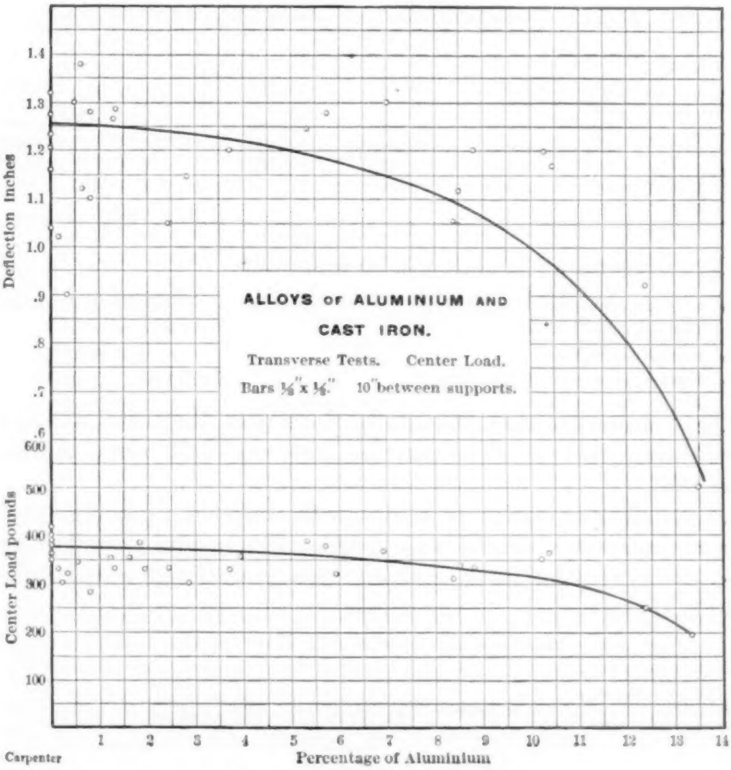

FIG. 142.

Magnesium is a silver-white metal of specific gravity of 1.74 and melting point of 446 degrees Fahr. The metal used was obtained in the form of rolled or drawn rods about .43 inches in diameter. Owing to the low temperature at which magnesium burns, it was not deemed advisable to attempt to cast it to standard test piece form, and so the rods were tested in tension just as they were supplied. Their length was about 8 inches,

and the extension was measured over a length of 4 inches. The material gave a fine cup fracture. It is very tough and bends with ease, emitting a cry like that of tin. It is easily tooled both with the file and in the lathe.

The following table gives the results of the tension tests for pure magnesium :*

Number of Test Piece	Diameter	Breaking Load Lbs.	Breaking Load Lbs. per sq. in.	Elastic Limit Lbs. per sq. in.	Extension per cent.	Modulus of Elasticity
1.........	.433	3,500	23,800	8,800	4.2	2,040,000
2	.433	3,250	22,050	......	...	1,860,000
3.........	.442	3,200	20,900	10,780	1.8	2,060,000
4.........	.435	2,900	19,500	8,400	2.5	1,830,000
5.........	.424	3,500	24,800	7,090	3.1	1,930,000
6.........	.432	3,300	22,500	.... ..	2.3	....

From the above table it will be seen that:

The average breaking strength is.... .... 22,250 lbs. per sq. in.
The average elastic limit is............................ 8,870
The average elongation is............................ 2.8 per cent.
The average modulus of elasticity is. 1,945,000

It is noticeable that though the density of the metal is only two-thirds that of aluminium it has one half more tensile strength.

A satisfactory series of alloys with different proportions of aluminium was obtained and tested. The results are given in the accompanying table, and are also plotted out graphically in Fig. 143.

ALLOY OF ALUMINIUM AND MAGNESIUM.

Number of Test Piece.	Percentage of Magnesium.	Specific Gravity.	Breaking Strength lbs. per sq. in.	Elastic Limit lbs. per sq. in.	Modulus of Elasticity.
1	0	2.67	13,685	4,900	1,690,000
2	2	2.62	15,440	8,700	2,650,000
3	5	2.59	17,850	13,090	2,917,000
4	10	2.55	19,680	14,600	2,650,000
5	30	2.29	5,000	.. ...	....

* For earlier work on properties of magnesium and its alloys, see "Materials of Aëronautic Engineering," *Transactions Aëronautic Congress*, Chicago, 1893; also *Sibley Journal*, April 1894.

"Magnesium as a Constructive Material," *London Machinery*, May, 1896; "Industries and Iron," May 22, 1896. Also Thurston's "Materials of Engineering," vol. iii., pp. 94–561.

The addition of magnesium to aluminium in increasing proportions was found to make the alloy more brittle; with 30 per cent. of magnesium it was so brittle as not to show any elastic limit.

The attempt to form alloys with copper, brass, or bronze containing more than one per cent. of magnesium were not successful. Several test pieces containing one per cent. or less were

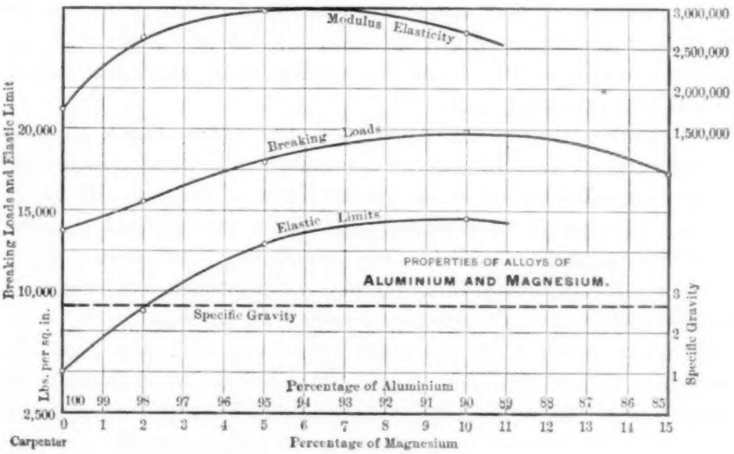

FIG. 143.

cast, but in every case the presence of cavities prevented the exact determination of their strength.

No alloys could be formed with iron, the magnesium always appearing in the form of globules in the interior of the metal.

It will be noted, from the study of results given, that the addition of small amounts of magnesium improved the tensile strength of aluminium and also decreased the specific gravity. The magnesium, on account of its tendency to burn, is a difficult metal to alloy with the aluminium, and for that reason, although this alloy presents superior qualities to that of pure aluminium, as well as on account of its high cost, it probably would not now enter into any commercial use. It was found almost impossible to make alloys which contained small percentages of aluminium. None were tested.

Aluminium, Tin, and Special Alloys of Aluminium.

An investigation of the strength of aluminium, tin, and certain special alloys of aluminium were made by S. R. Leonard and

J. H. Schnepel in 1895, the results being given in the accompanying table. This investigation gives the strength and other properties of pure aluminium, in either cast or rolled specimens, and of various alloys with tin, copper, and other metals. The scale of hardness employed is the same as that at the Watertown Arsenal and is proportional to the cube of the indentation of a certain pyramidal punch under a standard load of 4,400 pounds.

The strength of the aluminium tin alloys with from 2 to 10 per cent. tin show a slight maximum at about 6 per cent. of tin; they are, as a rule, however, weaker than pure aluminium and of little practical value.

The copper aluminium alloys, on the other hand, show a decided increase in strength, as compared with pure aluminium, due to the addition of small percentages of copper. Thus, in the cast specimens, pure aluminium has a strength of slightly over 12,000 pounds, while an alloy containing 7 per cent. copper has a strength of more than 50 per cent. greater. The rolled specimens show proportionately as great an increase.

The alloy marked SCA, which contains 75.7 per cent. of aluminium, 3 per cent. of copper, 20 per cent. of zinc, and 1.3 of manganese, is an excellent casting metal, having a strength of of over 35,000 pounds per square inch, and a specific gravity slightly above 3. It has, however, very little ductility.

An alloy containing 96.5 per cent. aluminium, 2 per cent. copper, and 1.5 per cent. of chrominium is very little heavier than the pure aluminium, and has a strength of 26,310 pounds per square inch.

The tensile strength of commercially pure aluminium, which is understood to be over 99 per cent. pure, has been found to vary in different samples obtained from the manufacturers from about 12,000 to 15,000 pounds per square inch. This difference is thought to be due to mechanical structure by the manufacturers, and it has been noted that in the last two years the strength of the samples has run quite uniformly near 15,000 pounds per square inch.

The general investigation of the subject indicates that all the alloys of aluminium, at ordinary temperatures, possess little elongation whenever the aluminium is in excess of the other ingredients, but that many of these alloys possess great strength, low specific gravity, and are admirably adapted for use in making castings.

The following tables give the strength and other properties of various aluminium alloys, as referred to above.

Character of Alloys.						Strength Pounds per Sq. Inch.			
	Mark.	Composition and Remarks.				Tension.		Transverse.	
		Al.	Cu.	Tin.		Elastic.	Max'm.	Elastic.	Max'm.
		per c't.	p. c.	p. c.					
Cast.	*P*	100	..	..	....	4,000	12,055	2,345	
	XG	93	7	..	....	6,250	18,555	9,000	25,250
	S. C. A.	75.7	3	..	20% Zinc., 1.3% Man.	....	35,075	....	23,420
Rolled.	P_1	100	..	..	1 inch bars	12,500	17,185	17,154	
	P_2	100	..	..	¾ "	....	....	18,870	
	XB	98	2	..	1 "	9,000	18,647	13,720	
	XB^1	98	2	..	¾ "	....	....	18,870	
	XD	96	4	..	1 "	16,000	23,045	22,300	
	XD^1	96	4	..	¾ "	....	....	30,880	
	TAXB	96.5	2	..	1½% Chrominium.	19,000	26,310	26,313	
Cast Tin Alloys.	*A*	98	..	2	....	2,150	8,622		
	B	96	..	4	....	2,400	9,565		
	C	94	..	6	....	2,250	9,315		
	E	92	..	8	....	2,000	7,270		
	D	90	..	10	....	1,750	7,352		

Mark.	Modulus of Elasticity. Lbs. per Square Inch.		Resilience. Inch—Lbs.		Elongation Per Cent. (Tension Pieces).	Reduction of Area Per Cent. (Tension Pieces).	Hardness (Relative)	Specific Gravity of Specimen.	
	Tension.	Transverse.	Tension (Modulus)	Transverse (Actual).				Tension.	Transverse.
P	8,385,000	8,440,000	2.06	.51	5.62	10.93	3.61	2.670	2.654
XG	11,115,000	8,065,000	2.80	7.9	1.00	3.08	12.87	2.830	2.810
S. C. A.	9,685,000	8,060,000	85.75	57.7	.15	1.77	35.56	3.117	3.055
P_1	9,780,000	10,110,000	7.4	34.8	8.49	38.30	7.12	2.710	
P_2	....	10,000,000	....	29.6	......	.....	6.94	2.715	
XB	9,505,000	10,330,000	4.75	17.0	19.49	39.02	6.79	2.725	
XB^1	....	9,600,000	....	30.4	......	.....	12.30	2.756	
XD	10,440,000	10,595,000	15.0	41.0	3.62	10.10	12.42	2.774	
XD^1	....	10,070,000	....	79.5	......	.....	13.35	2.773	
TAXB.	9,850,000	9,813,000	23.6	56.0	1.31	9.78	14.09	2.759	
A	5,435,000	....	....	....	4.00	8.64	3.71	2.689	
B	6,210,000	....	....	....	5.38	6.86	3.74	2.739	
C	5,035,000	....	....	....	5.19	7.97	3.49	2.771	
D	5,175,000	....	....	....	3.06	5.41	3.33	2.804	
E	6,675,000	....	....	....	3.87	8.89	3.09	2.856	

DISCUSSION.

Mr. Henry Souther.—Professor Carpenter has made a statement in regard to one of the copper alloys, and also in regard

to this alzinc, which, if taken just as made, seems to me of great value; that is, "that they will not tarnish on exposure to air." I have been searching for alloys which do not tarnish, and have found that copper and nickel, copper, aluminium, and nickel itself, and aluminium itself, all tarnish. To be sure they do not rust and go to pieces, but they do tarnish so much that it is necessary to clean them. I would like to ask Professor Carpenter if these alloys are not subject to the same slow change of color.

Professor Carpenter.—I am very glad indeed to have my attention called to that statement. The metal tarnishes just about the same as tin or aluminium does; that is, it loses its lustre after a time and then seems to remain in a permanent condition.

Mr. H. H. Suplee.—In regard to this matter of tarnishing, about which Mr. Souther has spoken, there have been lately in France a number of experiments made with an alloy of nickel and steel of much higher proportion of nickel than ordinarily made, which shows a very low degree of change of length for change of temperature, and it is claimed to retain a polish for a very long time. You probably know of Guillaume's experiments. The alloy is about 36 per cent. of nickel and the balance of steel, and it has so very low an expansion coefficient that it has been suggested to use it for measures of length. It will scarcely vary at all under the ordinary atmospheric changes. The tests of temperature were made by immersing the bar in water and then changing the temperature of the water, and after that the polished bar was taken out and simply allowed to lie without being turned up, and did not lose its polish in three or four months.

Professor Carpenter.—I should say that this metal will hold its polish three or four months very nicely, but after that it begins to get dull.

Mr. Charles W. Baker.—We already know that what is known as aluminium bronze, with about 90 per cent. copper and 10 per cent. aluminium, is an alloy of excellent qualities, although it is rather difficult to work. I would like to ask Professor Carpenter if he found anything in his researches which has led him to think that the addition of tin to this alloy (which is practically what his best compound of aluminium, copper, and tin involves) improved the metal in any way. I would also inquire

whether the best alloy of aluminium and zinc, which he describes, could be worked when heated, so that it could be rolled into plates, rods, etc., or stamped and drawn like brass.

Professor Carpenter.—In relation to the working of alzinc we have found out from recent experiments that if it is heated to about 400 degrees it becomes quite ductile and works quite readily under the hammer, and I think will prove to be in condition to be rolled. Experiments are in progress for rolling at that temperature. If it is heated higher than that it becomes brittle; it does not seem to reach the ductile point until it gets to about that temperature.

I would say that the addition of tin to the copper-aluminium alloys does not seem to have given especially good results as a general thing. Aluminium and tin do not seem to alloy well together, nor is the alloy of any particular value; and the addition of tin to the aluminium-copper alloy is only of advantage in increasing ductility. The aluminium-copper alloy, which is about 85 per cent. copper and 15 per cent. aluminium, is fully as strong, and my recollection is that it was two or three thousand pounds stronger per square inch for tensile strength than the aluminium-tin copper alloy. But the latter was a little more ductile, and we thought, on the whole, possibly a little better for many uses, since it can be more readily worked.

Mr. Thos. R. Almond.—I would like to ask Professor Carpenter if he can tell us anything about the porous condition of the surface in the specimen of alzinc seven inches in diameter. I notice there is a porous condition reaching, perhaps, an eighth of an inch below the surface. This may possibly be due to gases which came in contact with the surface of the metal. Is there any way which you have tried to avoid this? The surface is what is most needed to be solid in finished work.

Professor Carpenter.—The specimen which was handed around, and to which Mr. Almond refers, was cast simply in a sand mold—poured right into the sand; and I think possibly that the porosity near the outer edge is due to cooling strains. We have had less difficulty with this metal than with brass in making sound castings and in having them free from pores. We have used it extensively when pores would be found if present.

Mr. Almond.—Has it been cast with a very high riser, so as to give pressure?

Professor Carpenter.—We have had a plate half an inch thick

under 5,000 pounds liquid pressure per square inch, without the least indication of porousness; that is the highest pressure we have had on any castings. In that case there was about $2\frac{1}{2}$ inches of surface exposed to the pressure, but the extreme edge of that casting was not exposed. No porousness whatever was found. You must understand, of course, that I am talking about castings made in a college workshop, which has no skilled men, the casting being done by students who have had all their training in our foundry. Consequently the results that we get are not as good, I think, as should be obtained in other foundries. We have made no castings with sprues larger than 6 or 8 inches.

Mr. Almond.—We usually find the porous condition nearer to the centre. The solid part of the casting is more likely to be at the surface, owing to shrinkage in cooling. In the metal shown the porosity would seem to be due to the absorption of gases which come from the sand.

*Professor Carpenter.**—I should have to answer the question simply in the light of our experience, and that is that we can make sounder castings with this metal than we can with brass.

The specimen to which Mr. Almond refers is a section of a pig of this metal cast in sand, without any sprue head, and is about 4 inches in diameter. I attributed the small checks near the outer edge to the fact that the outside cooled much sooner than the centre, and that finally the shrinkage of the centre mass caused the outside to check somewhat. It is quite certain that there is no especial difficulty in getting sound castings, even when they are very thin, with this metal.

Since writing the article, a method of rolling and drawing this metal has been perfected, there being no especial difficulty at a temperature of about 400 degrees F.

My attention has recently been called to the fact that many foundrymen have very little skill in mixing metals, by several failures which have been made in attempting to make the simple aluminium-zinc alloy, as described. For that reason I should advise those who desire to use it, to correspond with the Pittsburg Reduction Co., at Pittsburg, Pa., from whom I believe it can be obtained at cost prices.

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* Author's Closure, under the Rules.

DCCLXXV.*

WHAT IS THE HEATING SURFACE OF A STEAM BOILER?

BY CHARLES WHITING BAKER, NEW YORK CITY.

(Member of the Society.)

It is a fact which is now generally understood by engineers and all who have to do with steam power plants, that the power of any boiler, or more accurately the amount of steam which it can furnish in a given time, depends first of all upon its area of heating surface. Of course the amount of steam which a square foot of heating surface will produce varies between very wide limits, and is affected by a multitude of conditions. It is also true that heating surface is no more essential than the means for supplying the heat—that is to say, a furnace of sufficient size and grate surface to burn the fuel, and draft sufficient to supply the furnace with the necessary air. The furnace and the chimney, however, are not necessarily parts of the boiler at all; their function is merely to supply the heat, and the function of the boiler proper is to transfer as much as possible of this heat to the water which it contains. Both the amount of heat which it can transfer in a given time and the proportion of the total heat generated which can be transferred vary with the area of the heating surface exposed. In other words, both the capacity and the economy of a steam boiler depend directly upon its area of heating surface.

Evidently, then, the area of the heating surface of a boiler ought to be determined with a fair degree of accuracy. The designer of the boiler must know it, if, with any degree of precision, he is to adapt the boiler to the work which it has to do. The seller of boilers must know it, if he is to be sure of fulfilling his guarantees of capacity or economy; and the purchaser of boilers should know it, in order to determine what he is getting for his

* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

money. As a matter of fact, a very large proportion of the boilers bought and sold are actually bought and sold by their heating surface. The prices asked for and quoted may be the price per horse-power, but the horse-power is determined directly from the heating surface, the number of square feet allowed to a horse-power varying from 5 to 14, according to the type of the boiler. Again, in comparing the work done by different boilers, the relative heating surface is always taken into consideration.

We need go no further for proof that accurate determination of boiler heating surface is a desirable thing. But we have now to notice the remarkable fact that in computing boiler heating surface, an error of from 7 to 17 per cent. is made by a large proportion of steam engineers and boiler manufacturers. The error to which I refer consists in taking the surface in contact with the water, instead of that exposed to the fire or hot gases, as the heating surface. If the heating surface is flat, of course the areas are the same; but boiler heating surface is in most cases made up of tubes, and the difference between the interior and exterior surface of a boiler tube is as much as 17 per cent. of the interior surface in the case of a 1-inch tube and is about 7 per cent. in a 4-inch tube.

The error arises in the first place from a failure to appreciate the *fact that the heating surface exposed to the fire is the actual heating surface of the boiler, on which its capacity depends.* A clear understanding of this fact is so important, and it has been and is so generally mistaken by engineers and writers of engineering works, that the writer ventures to submit a discussion of the elementary principles on which this assertion is based.

In Fig. 144, suppose we have an iron plate 1 inch thick, on one side of which is flowing a current of hot gas at a temperature of, let us say, 1,000 degrees, and on the other side is a body of water in a steam boiler at a temperature of 300 degrees (corresponding to a gauge pressure of steam of about 52 pounds).

Now the heat in passing from the hot gas on the side of the plate to the water on the other meets with three different resistances as follows:

(1) Resistance in passing from the gas to the surface of the plate.

(2) Resistance due to the passage through the plate.

(3) Resistance due to the passage from the other surface of the plate to the water.

That one of these resistances which is accurately known is (2), the resistance in the passage through the plate. The heat conductivity of metals has been carefully determined by experiment in physical laboratories, so that if we know the actual temperatures of the two surfaces of a plate and its thickness, we can at once determine how much heat is passing through a unit area in a given time. On the other hand, if we know how much heat is passing through the plate, we can determine what is the difference of temperature of its two surfaces. Let us solve an example of the latter sort: Suppose the plate is transmitting heat enough to evaporate 3 pounds of water per hour from and at 212 degrees per square foot of its area, or about the average rate that the heating surface transmits heat in an ordinary stationary boiler. Since 965.7 heat units are required to transform a pound of water at 212 degrees into steam at the same temperature, the plate will transmit 3 x 965.7 = 2,897.1 heat units per square foot per hour, or for convenience let us say 2,900 heat units.

Now experiments on the conductivity of metals have shown that an iron plate 1 foot square and 1 inch thick whose opposite surfaces are kept at a uniform difference in temperature of 1 degree Fahr. will transmit in an hour 473 British thermal units.* Hence to transmit 2,900 British thermal units per hour, the difference in temperature of the two sides of the plate will be 2,900 ÷ 473 = 6.13 degrees.

I doubt not it will surprise many to learn that so small a difference of temperature between the two surfaces of an iron plate is sufficient to cause so large an amount of heat to flow through it; but the coëfficient for the heat conductivity of iron on which it is based is the result of many experiments by the most eminent physicists, and is accepted as correct by the best scientific authorities, and there is no reason to doubt its accuracy.†

In studying our present problem, however, the exact accuracy of the coëfficient is a matter of no particular importance. We just found that boiler heating surface 1 inch thick, when transmitting 2,900 heat units per hour, will have a difference of temperature on its two sides of 6.13 degrees Fahr. But we never

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* See Ganot's "Physics," 13th ed., page 378.

† Many engineering text-books and pocket-books still quote Rankine's formula and Peclet's coëfficients for heat conductivity; but the latter have been found by the more careful research of modern physicists to have been largely in error.

have heating surface of such thickness in steam boilers. The shell heating surface in internally fired boilers is seldom over $\frac{5}{8}$-inch thick. Furnaces and fire boxes are made of $\frac{1}{4}$ inch to $\frac{3}{8}$-inch plates, while tube heating surface is from $\frac{1}{16}$ to $\frac{1}{8}$-inch thick. We see then that the actual difference of temperature between the two surfaces of a boiler tube transmitting heat at the rate already named will be from $\frac{1}{8}$ to $\frac{1}{16}$ of 6.13 degrees, or in round numbers from $\frac{3}{8}$ degree to less than 1 degree Fahr. As the eminent physicist Lord Kelvin has said, for all practical purposes, we may consider that the heating surfaces of steam boilers conduct heat as if they were no thicker than paper, or as if the metal were of infinite conductivity. It will be seen also that an error of 50 per cent., or even of several hundred per cent., in determining the coëfficient of conductivity of iron, even if such an error were probable, would make no practical difference in this conclusion.

There are many facts of practical importance to be drawn from this. For example, in its light we can readily see how little reason there is to expect any greater economy in locomotive boilers with brass or copper tubes and fire boxes than in those of steel. Yet we still hear the superior conductivity of copper urged as a reason why English railways stick to the use of copper fire boxes.

Turning again to Fig. 144, we know now that the two surfaces of the plate, (if we conceive its thickness reduced to that of an ordinary boiler tube,) will have only a trifling difference of temperature. Next let us discuss the relative heat-absorbing powers of the water on the one side of the plate and the hot gases on the other. It is to be kept clearly in mind that the temperatures of the two sides of the plate which we have just considered are the temperatures of the skin of the plate itself, which is quite a different matter from the temperature of the air or the water in contact with the plate.

If this is clearly understood, it will be easy to understand that the actual temperature of the plate itself depends on the relative heat-transmitting power of the fluids on its two sides. If these fluids were the same on the two sides, and were at the same temperature and under the same conditions as respects mobility, then the plate temperature would be a mean of the temperatures of the fluids on its two sides. But in the case shown in Fig. 144, since water is many times as efficient as air or furnace gases in

absorbing heat, the plate temperature will be nearly the same as that of the water and far below the temperature of the hot gases.

This is a fact which is a matter of common knowledge; and yet it has been overlooked by many engineers and by engineering writers; and because it has been overlooked is one main reason why engineers have not always insisted on the fire side of tubes being considered the heating surface of steam boilers.

Let us review some of the facts which show the relative heat-

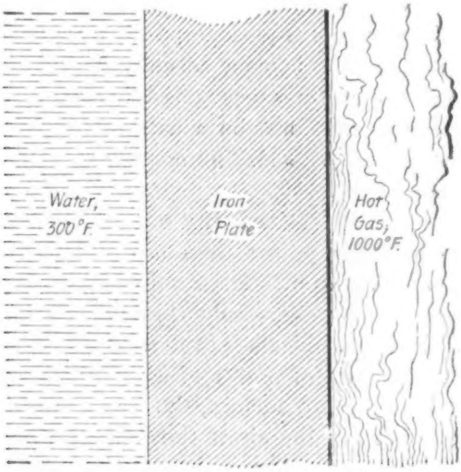

FIG. 141.

absorbing power of water and gases: Take an iron rod and heat it to redness, then let it be held still with only the air in contact with it, and see how long a time elapses before it is cool enough to be touched. Heat the rod to redness again and then plunge it in water and again note the time before it can be touched. We have then a very rough approximation of the relative heat-absorbing powers of air and water.

Again, experiments have been conducted to determine the temperatures to which a metal plate could be heated when one side was in contact with water. The temperature was determined by inserting in it plugs of various fusible alloys, and the fire side of the plate was then subjected to the most intense heat that a powerful blow-pipe could produce. So long as the water side

of the plate was clean, it was impossible to melt the fusible plugs.*

The most striking illustration, however, which the writer has ever seen of the large heat-absorbing power of water, as compared with air, was an experiment conducted by him for another purpose some years ago. A vessel having a single vertical tube of about 2 inches diameter was filled with cold water (45 degrees to 50 degrees Fahr.); the hot gases from a large oil lamp or a Bunsen burner at a temperature of some 1,000 degrees or more were then passed up through the tube. The surface of the tube exposed to the hot gases was kept so cold by the water on the other side that drops of dew were condensed upon it from the hot gases, and the interior of the tube became actually coated with dew, which remained until the water was warmed to about 60 degrees. I advise anyone who may not be convinced as to the enormous heat-absorbing power of water as compared with gases, to try this simple experiment.

It is very easy to understand why water should have so much greater heat-absorbing power than air. The specific heats of water and air are as 1 to 0.23 for equal weights; but since air at ordinary temperatures weighs only $\frac{1}{812}$ as much as an equal volume of water, if we consider a thin film of air in contact with a hot surface and a film of water of equal thickness and area in contact with a similar hot surface, the water would absorb 3,530 times as much heat as the air if the temperatures of each were raised an equal amount. Again, the relative heat conductivities of water and of air, according to Lord Kelvin, are as 40 to 1. On the other hand, in the transmission of heat from a surface to a fluid, the mobility among the particles of the fluid, whereby fresh portions of it are constantly brought in contact with the surface, is a matter of great importance, and in this respect air, of course, has a considerable advantage.

The writer has been unable to find any trustworthy figures for the relative heat-absorbing power of air and water; and the prac-

* It may be well to point out that this method of determining the maximum temperature reached by the plate is subject to more or less error on account of the obstruction to the passage of heat from the plug to the metal of the plate (the plug being merely embedded in the surface of the plate and not passing entirely through it). Any joint between two metal surfaces interferes with heat conductivity just as it does with electrical conductivity. The amount of interference depends upon how intimate the contact is between the metals, the amount of oxides (if any) between them, etc.

tical importance of their accurate determination would be trifling, for we know in a general way and from the examples already cited that water absorbs heat very many times more rapidly than air, so many times that in the case of a thin metal plate, such as a boiler tube, transmitting heat from furnace gases on the one side to water on the other, we can be quite certain that the temperature of the metal plate is at most only a few degrees warmer than the water in contact with it.

In other words, in any steam boiler with clean heating surfaces we can assume the temperature of the fire side of the heating surface to be practically the same as that of the water in the boiler. Perhaps it may be 1 degree more; perhaps it may in some cases be 20 degrees, or possibly 30 degrees, more. The difference is of no practical importance, since in the few cases where so large a difference as 20 degrees or 30 degrees may possibly exist, the temperature of the fire to which the surface is exposed is greater by probably 2,000 degrees or more than the temperature of the plate.

If, now, it is clear that the fire side of the boiler tube or flue is at practically the same temperature as that of the water in the boiler, the reader will have little difficulty in comprehending that this surface, and not the surface on the water side, is the real heating surface of the boiler, which measures its capacity of making steam.

The great resistance to the flow of heat in any steam boiler is in getting the heat from the hot gases into the surface exposed to them. Compared with this, the resistance to the passage through the plate and the resistance to the passage from the plate into the water are mere trifles. If we increase the surface exposed to the hot gases, we shall increase the capacity of the boiler to absorb heat; but if we leave this surface the same and increase the surface exposed to the water, the amount of heat transmitted in a given time will be practically the same.

The case can be made still more clear perhaps by an analogy to the flow of water through pipes. If we have a length of 1-inch pipe, connected to two lengths of 12-inch pipe, and allow water to flow through them under a head, it is clear that the flow will be determined by the resistance of the 1-inch pipe. If we enlarge that, we shall enlarge the flow; but if we leave that alone and enlarge either or both the 12-inch pipes, the flow will be practically unchanged.

The area of the fire side of the tube is what determines the heat-absorbing power and the steam-making capacity of the boiler. If we can cause this to take up more heat in any way, we shall increase the power of the boiler. The Serve tube, with its ribs extending into the hot gases, increases the interior surface of the tube, and thus its capacity for absorbing heat. If, however, instead of putting ribs on the fire side of the tube, we put them on the water side, we increase the surface exposed to the water, but we make no increase of any practical importance in the amount of heat transmitted. In a similar way, the curved form of the tube, which causes the surface exposed to the water to be greater than that exposed to the fire (in fire-tube boilers), effects no increase in the amount of heat transmitted. The real heating surface, which determines the amount of heat transmitted, is the surface exposed to the fire.

In the preceding discussion it has been supposed that the heating surfaces were clean on both sides. As a matter of fact, heating surface is almost invariably more or less coated with soot or ash on the fire side and with scale on the water side. If the preceding discussion has been carefully followed, it will be clear that the transfer of heat will be much more interfered with by the deposits on the fire side than by deposits on the water side. To use again the analogy of the water pipes, a half-closed valve in the 1-inch pipe would have far more effect than a half-closed valve in the 12-inch pipe. It is no part of the purpose of this paper to excuse lack of care in keeping boilers free from scale; but it is nevertheless quite certain that a thin scale on boiler tubes does not interfere in any noticeable degree with the capacity or economy of a boiler, while the coating of the fire side of the tubes with a flocculent deposit of soot does certainly interfere in a marked degree with a boiler's steam-making capacity. Of course, a thick scale on the water side of tubes or other heating surface, or any other material which acts as a non-conductor, may considerably obstruct the flow of heat. If it does this, the temperature of the heating surface itself will at once be raised, and may reach a point, as happens sometimes with the shells of externally fired boilers and with the furnaces of marine boilers, where the metal may be so heated as to bulge or buckle.

It may be worth while in this connection to administer a puncture to that hoary fraud which has been repeated in technical literature and trade catalogues "ad nauseam." I refer to a table

purporting to give the loss of economy in per cents. for each $\frac{1}{16}$-inch of scale upon the heating surface of a boiler. In view of the fact that there are many varieties of boiler scale, varying widely in porosity and heat conductivity, and remembering that the thickness of scale in different parts of a boiler is never uniform, it hardly needs the discussion above to show the utter absurdity of this ancient "fake."

Another deduction of practical importance from the fact just set down, is that so far as the transmission of heat after the boiler is making steam is concerned, the circulation of the water in boilers is of a good deal less consequence than has been sometimes claimed. I do not mean by this that it is not worth while to make proper provision for circulation. There are possibly some parts of boilers worked with forced draft, such as the tube-plates of marine boilers, where it is so difficult for the steam bubbles to get away fast enough that we have a mass of foam instead of water in contact with the plate. Under such conditions, of course, the plate is bound to be heated; but I know of no evidence that this is any other than a rare occurrence, even in boilers which are pushed most severely. If anyone is inclined to stick to the old hobby that circulation is of great importance to economy, I advise him to consider the conditions in the narrow water space (about $3\frac{1}{2}$ inches wide) around a locomotive fire box, where the steam rushing up is directly opposed by the water going down. Let it be understood that I am referring to circulation only as affecting the transfer of heat and the consequent economy and capacity of the boiler. Good circulation is desirable to prevent unequal heating of the boiler, and consequent straining, and it may be of service in preventing deposits of scale and mud in places where they are least desirable; but that it has any appreciable effect on economy and capacity is not proved, and probably cannot be.

It has been demonstrated above that the surface exposed to the fire is the real heating surface of a steam boiler. Is there any good reason why this should not be generally adopted by engineers as the correct, and the only correct, method of computing heating surface?

The following are some reasons, good or bad, which are likely to be urged against this:

1. The makers of fire-tube boilers will claim that this gives the water-tube boiler makers an advantage. With the same number

of tubes in a boiler, of the same length, the water-tube boilers can show 7 to 11 per cent. greater heating surface. This is of course true; but is it not an advantage to which the water-tube boilers are fairly entitled? It must be remembered that nowhere in this discussion has it been claimed that there was any fixed heat transmitting value for heating surface. On the contrary, it is entirely certain that a square foot of heating surface in one type of boiler may have double the heat transmitting power of an equal area in another. Again, the relative facility with which heating surface can be cleaned of soot and ash counts for a vast deal, more than most steam users are accustomed to think. It certainly seems that the makers of fire-tube boilers have enough valid arguments to offer for their product without demanding the privilege of overstating their heating surface by 7 to 11 per cent.

2. Another argument offered for the use of the exterior surface as the heating surface is that this makes a given boiler show a larger heating surface than if the interior were taken. However much the argument may appeal to boiler manufacturers—and I hardly think they will take it very seriously—it deserves no weight with engineers. A foot rule is no longer for calling it 13 inches.

3. It is urged that practice is and has in the past been fairly uniform in accepting exterior area as the heating surface, and it is best to stick to a uniform practice, even if it be in error, than to change. If the practice were actually uniform, there might be reason in this argument; but while the majority of engineers probably use the exterior surface of tubes in computing heating surface, there is a very respectable minority which insists on the correct method of computation, and this minority shows no signs of decreasing.

4. As the outside diameter of the tube is even inches and the thickness of tubes varies, it is easier to compute the exterior heating surface than the interior. Probably this is one of the principal reasons why the outside surface has so frequently been taken; but in these days of tables and pocket-books and aids to computations, so trifling a matter as computing the interior area of a tube ought not to be an excuse for perpetuating an error. As a matter of fact, it will generally be less labor to do this than it is to figure the cost of the tubes with the numerous series of discounts which are frequently found on hardware bills in these days.

It appears to the writer that none of the arguments which have been cited in favor of computing the exterior surface of tubes as their heating surface are sound enough to justify engineers in perpetuating this error. If, however, for the sake of uniformity or ease of calculation, it should be thought best to use the exterior surface of tubes in computing heating surface, the fact that this is not the real heating surface ought to be kept clearly in mind. Misconception and wrong ideas on this point have been responsible for not a few mistakes and absurdities in the design of steam boilers.

DISCUSSION.

Prof. S. W. Robinson.—The entire resistance in passing from the hot gases to the water includes that in getting the heat from the gases into the plate, the resistance of the metal of the plate itself, and finally the resistance in passing from the plate to the water. The resistances in passing through the plate and from the plate to the water are comparatively small. It is probably well known that in analyzing the case we treat of the three resistances, but in the final formula for practical use all the resistance is dropped from the formula except the resistance in passing from the gas into the metal.

Mr. Gus C. Henning.—I would like to discuss the point whether the plates are all heated the same on the fire and the water side. If we have a straight, flat surface, the fire acts on the sheet uniformly. It begins to eat away the sheet exactly where the scale has been broken off of the sheet. Where there is still some scale the sheet is not eaten away as rapidly as at the adjoining points, and if put in service the sheet will wear that way unless there are some soft spots in the sheet.

With respect to the other point, "whether the sheet is heated uniformly through and up to the temperature of the steam on the other side," I want to point out these facts: Boilers are not like flat sheets; they have seams and rivet heads. In firing up, the boiler gets pretty hot inside, and the edge of the lap becomes actually red hot and the rivet heads sometimes show redness, provided there is a plate on the back of it so that the heat does not go directly into the water. At points of the fire side away from the edge of seam the sheet will not be red hot, but the temperature will be uniform. But if you look into the furnace of a locomotive boiler or any boiler which has a pretty hot fire,

you will find that these rivet heads are positively red hot on the extreme top, and the edge of the overlapping seam is red hot. One result is that after a boiler has been in service for some time —especially a locomotive boiler—the edge of plate is split from the rivet out. The other day I saw a boiler which had exactly one-fifth of the rivet holes cracked from the rivet out to the edge. That is produced by the fact that the sheet was red hot. These rivets were driven in so as to plug the hole thoroughly, and had expanded the metal a little bit. When the metal gets red hot it is so much softer than the body of the rivet inside, that it will simply burst the edge of the sheet. Sometimes those cracks extend beyond the other side of the rivet, causing leakage. Any one can see that the top of head of the rivets is red hot, if blue glasses are used; some can see it without, of course. It can be seen that some stay-bolt heads are red hot, and by looking into a furnace that has been running for some time, these heads will be seen to have been burnt off. I mean in a case where a proper head has been put on a stay-bolt. There is no question about the edge of lap, because a look into a locomotive boiler shows edges of these seams red hot. There is no question that when they are red hot and water is on the other side, the temperature on the fire side will be much higher than on the water side. I do not deny that the fire side ought to be the heating surface for calculation, but at the same time there is a great difference of temperature in the different parts of sheets of the boiler according to where it is measured. In my previous statement, which Mr. Baker did not understand, we have another thing. The boiler on top was arched by brick, which absorb the heat very rapidly, and at the bottom the shell is in contact with fire; but it is not that which produces the expansion of the boiler; it is the change of shape.

Mr. Chas. W. Barnaby.—I am very much inclined to doubt Mr. Henning's blue glasses. I think he must have got some red glasses on by mistake. I have frequently looked under boilers and noticed that the rivets did look red hot. But I always attributed it to the reflection of the fire—a sort of a red glow. There is frequently a red glow over everything at sundown. In the same manner the red glow of the furnace fire is reflected from the rivets. I do not think it would be possible under any conditions of fire, under any ordinary thicknesses of metal, and ordinary construction, placing of rivets, etc., to get the outer end of the

rivet red hot or to a point anywhere near approaching a red heat, with water against the inside. Of course, if the boiler was badly scaled it might be different, and you might get the sheet red hot. We know that they do get red hot in some cases, as is shown by the occasional bagging down of the shell over the fire. If the rivets and edge of the sheet really did get red hot, instead of the cracking of a shell at the rivets being a comparatively rare exception it would become a rule, and I think you would find it on every boiler. As a rule, where you find those cracked sheets you can make up your mind it is due to one of two things: the boiler has been allowed to get very dirty, or else it has been made of very poor material.

Mr. T. W. Hugo.—I would like to ask the gentleman who spoke if he has ever found those cracked sheets without an accompanying elongation of the rivet hole. I have come across a great number of cracked sheets, in our country, and invariably found a rivet hole out of shape. In a great many cases the cause of the deformation of the hole could be traced directly to the pull of the sheet, resulting from the corrugation of the plate when overheated through an accumulation of dirt or some oil; but in every case the crack in the plate from the rivet hole to the edge has been accompanied by an elongation of the rivet hole, and my conclusions were that they were due to the extraordinary pull or strain thus put on the sheet under abnormal conditions; and where those corrugations or some other mark of overheating did not appear, I blamed it on the severe initial strains due to poor workmanship.

Mr. E. D. Meier.—I think myself that my colleague Henning has made a mistake in supposing that he saw those rivet heads red hot. I have often looked into the inside of a locomotive boiler and I have never seen them red hot. I think you would be apt to be misled, for this reason—there will be always a great amount of soot and ash collected on those rivets, and that will glow. That may possibly get red hot, and that will assist the optical illusion—the reflection from the fire itself. I do not think if you were to suddenly deaden the fire that you would see anything red hot in the locomotive boiler. It is true that not so much the rivet heads as the outer plate will be hotter than this inside plate. That is proved by the long experience on the Mississippi River and its tributaries, which has shown that it is not safe to carry the metal more than $\frac{26}{100}$ of an inch thick; and

latterly, since they have been using steel altogether instead of iron, they have increased that to $\frac{3}{10}$ of an inch. But anything thicker will be apt to burn out on the laps. No doubt the scale has something to do with that. The presence of scale has quite an influence. It depends, of course, on the kind of scale. Anything that will prevent the water from actually touching the metal on the inside is going to have that effect. Now a very thin oil film, so thin that you can hardly measure it, will have more effect than $\frac{1}{8}$ of an inch of hard scale. Why? Because the scale always will permit some water to get through it. It is always soaked with water. But the oil will not. Another point in regard to the circulation: I agree fully with the author of this paper as to the desirability and the correctness of taking the outer surface of the tubes—that is, the fire surface of the tubes; I should say the inner surface in the case of fire-tube boilers, and the outer surface in the case of water-tube boilers. The fire surface of the tubes is the heating surface. But he errs when he says that the circulation has nothing to do with it. It has everything to do with it. His own illustration shows that. Take that illustration of the blacksmith who thrusts a rod into a tub of water to cool it; he never holds it steady, he moves it about. Why? Because the moment that a film of steam or hot water forms on it it will not cool so quickly. Take again his illustration of the locomotive boiler. Has any one ever seen a locomotive boiler standing idle on the track, or on skids in a shop, do as much work as it will when it is in motion, when every bubble of steam is shaken loose as soon as formed? The same with a marine boiler. You cannot get as much work out of a marine boiler on shore as you can on a vessel. The circulation has everything to do with it. That is the life of a water-tube boiler, and that is the reason the water-tube boilers are everywhere in the lead. The circulation brings fresh water right to the point where it may draw off the heat, and I think the circulation on the other side is just as important. If you have simply dead heat there you won't get as much out as if you had the heat constantly sweeping through, so that the first volume of hot gas is swept away as soon as cooled, and a fresh volume takes its place.

Mr. William Garrett.—As I understand it, the paper we are discussing just now is, "What is the heating surface of a steam boiler?" We are drifting into the subject as to whether or not

a rivet gets red hot under a steam boiler. In reading this paper I thought the main object of the author was to settle a long dispute between the fire-tube and the water-tube boilers, as to which of the two boilers had the more heating surface. Another thing he wanted to impress upon our mind is that it is necessary for a manufacturer to know the heating surface of a boiler before he can know what he is getting for his money; and one would infer that the man who buys a boiler with the greatest heating surface gets the most for his money. Now I differ from the general way of looking at these things, that the heating surface of a boiler is everything that is required to show its merits, and I want to tell a little story in connection with this which will make my reason plain. A little boy who lived on a farm took a great interest in raising chickens. His parents encouraged him in this, built him a chicken coop, gave him some eggs and hens to start with. One day there was quite a fuss in the chicken coop, and the boy's mother looking over the fence saw Johnny was in the act of setting a hen upon some eggs. His mother said, "What are you doing, Johnny?" He replied, "I am trying to set this old hen." "Why, Johnny," said the mother, "you've got too many eggs. Let me see; you've twenty-four there; why, thirteen are enough." "I know that," said Johnny, "but I want to see the old hen spread herself." Now, there was a larger heating surface in the twenty-four eggs than in the thirteen, but of what use was that, seeing that the heating capacity of the hen was only equivalent to thirteen eggs? and I believe that boiler men are running somewhat riotous in the direction of heating surfaces of boilers, and not paying as much attention as they should to *the heating surface that can be applied to a boiler*. It is *results* that manufacturers look for, and one of the most economical things I know of in this direction, that of obtaining results from a boiler, was what I saw on the other side of the water, where they had a heating furnace applied to a boiler (one of our well-known water-tube boilers). They fired this furnace by hand, and the results they obtained were as follows: weighing the amount of coal they consumed and the quantity of water they evaporated, they found they evaporate eight pounds of water to one pound of coal; and the boiler gave its full rating as to horse-power capacity, and at the same time heated the material in proper shape to roll. This I think is the basis upon which boilers should be bought.

Mr. Suplee.—I think Mr. Baker is in error as to the small value of circulation. The ordinary method in the laboratory of determining specific heat is to heat a piece of metal and put it in water. We heat a piece of metal of a definite and known weight. We plunge it into the water and we note the rise of temperature of the water. Now it is utterly impossible to get correct results in determining specific heat in that manner unless you have an agitator; and the laboratory instrument for that purpose is made so that the water can be agitated rapidly and the temperature can be noted to rise until the water has circulated and practically every particle of water has come in contact with the metal. Lately Mr. Yarrow has made a number of experiments which were presented, I think, before the Institute of Naval Architects in London, concerning the effect of circulation on his water-tube boilers, and there, by the introduction of diaphragms in the lower drums and delivering the water into the outer rows of tubes under pressure, he succeeded in increasing the evaporation very materially by forcing the circulation. I think the figures rose to three, four, possibly five per cent. in the result, according to whether he assisted the circulation or allowed it to work out its own salvation.

Mr. W. W. Bird.—With regard to the question of the temperature of that part of the shell of a boiler which is exposed to the fire, I would say that from observations made in connection with experiments with various devices for preventing smoke, we have concluded that not only is the surface of the shell on the outside at about the temperature of the inside, but that there is a film or layer of gas in contact with this surface which is also at a comparatively low temperature. A small rod was introduced through a piece of pipe which protected the rod so that only the end was exposed at the desired point, and in this way a rough estimate was made of the temperature in different parts of the furnace, with the conclusions as stated.

Mr. LaForge.—There seems to be one view of this matter which has been left out of the discussion altogether. It is a well known fact that a water tube boiler, or a plain horizontal tubular boiler, will run but a very short time before the upper side of the water-tubes is covered with a certain amount of ash, and the lower side of the return fire tubes are carrying a certain amount of ash in the bottom. Now, what proportion of

these tubes is it proper to consider as heating surface? In illustration of this point, I will state a little experience that I have had with a Hazleton boiler, which may be of interest. The boiler was running under about 125 pounds of steam, when a six inch nipple blew out of its upper head. After the boiler had cooled down, I found that the water showed in the bottom of the glass water gauge, but on examination I found that the water had been out of two or three of the lower rows of tubes, the bottom side being burned, but where the ashes lay on them they seemed to be all right.

Prof. S. W. Robinson.—I think that attention should be called to this matter of strength of red hot rivet heads. In calculating the strength of a boiler we allow certain metal to resist the pressure, but I do not think it is customary to take that resistance on red hot metal. If the metal gets red hot for a considerable distance along a seam it would be very likely to fail, since there is a considerable strain under two or three hundred pounds modern pressure of steam. I think it would be rather dangerous business for people to be around in the neighborhood of a red hot boiler. I think a boiler should be so constructed that the metal sheets will not become red hot, on this score alone, of strength of the shell of the boiler.

Mr. Henning.—Those cracks always occur on account of some previous defect of the material, either by punching or drifting, or by caulking the edge, but they do not occur on the water side of the seams except in rare instances, but they occur in a great many cases on the fire side. That is such a well known fact, that if you look into any locomotive boiler (I don't care whether it has been in service two weeks or two years) you will find some cracks. If the boiler is heated up in the shop just for a trial you will find some such cracks. Whether the sheet has been wrinkled or the hole has been drifted or simply punched without reaming, you will always find those initial cracks. I have seen some few on the water side, but that was due to bad workmanship which should not have been tolerated. But the contact of fire with the sheets develops those cracks, and it is such a well known fact that I did not think I ought to bring it up in connection with the present paper, because I was simply talking of the conduction of heat from the surface through the sheet. I did not mean to say that the fire really caused those effects, but the fire simply developed them. But I

do not want it understood that I said that those cracks were initiated by the heat. They are initiated by bad workmanship mainly; sometimes by bad material, and the heat on the fire side of a double seam like that develops them.

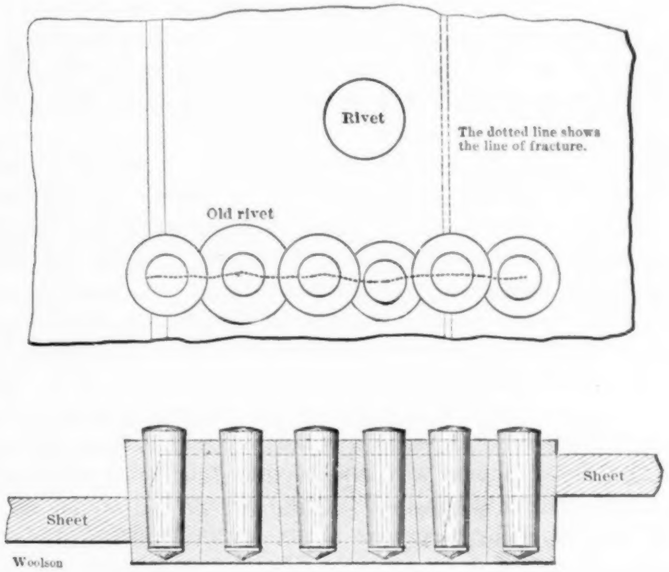

FIG. 145.

Mr. Jas. McBride.—Since the discussion has turned upon cracks, perhaps some of the members would like to know when they do get a crack of that kind how to close it. In a couple of boilers I have, there was great trouble with the fire box sheets cracking. They would crack from the rivet out to the outside edge, run in on the sheet as much as two inches, and leak very badly. Of course it would be very expensive to throw away the fire box, so I repaired it in this way (Fig. 145): I drilled the rivet out, which of course goes through the two sheets. I took the rivet out, reamed the hole out true, and tapped it with three-quarter inch pipe tap. I plugged the hole and drilled another hole here, plugged it with a soft steel plug, and on each side of this, drilled another hole about a quarter of an inch into the first one. I continued that process until I had drilled out all of the crack, out to the edge of the sheet. Those holes all tapped with half-

inch pipe tap and a soft steel plug screwed in as tight as it could be screwed, the square head was then sawed off true on the outside. Into each of these plugs I drilled a three-eighth inch hole. I did not drill through the plugs, understand, but nearly through and reamed them, tapering. I then made tapered pins of steel, and drove them into the plugs as hard as I could drive them, and have never had a leak since. I fixed four or five cracks in that way, and they are perfectly tight.

Mr. Henning.—I would like to give a little simpler method of doing that, which is the rule adopted by the French railroads. If you see a crack on the inside of a rivet, drill a little hole at its end and put a little plug in and caulk the crack either side of the rivet. If you can get on the inside, do the same thing there. But it may become necessary to put a patch on the whole business. But the first thing is to stop the crack by drilling a smooth, round hole, and then it won't continue.

Mr. LaForge.—I would like to ask you how much stronger it is after you do that than before.

Mr. Henning.—It is not a matter of strength. There is always an excess of strength in the seam, so that that is not the question. Of course a boiler is always weaker when it has cracks. Therefore, when the crack gets very bad a patch is put on it.

Colonel Meier.—I will say that I do not believe any such cracks ever occurred from bad workmanship or from the heat. It was no doubt bad material; for which reason, when I find a number of cracks like that occurring (referring to blackboard), though I think that is a very skillful and very ingenious method of repairing—but I take such a sheet out and condemn it, because I know that the material of the plate is worthless. I do not believe any cracks have ever occurred, even where the sheet is simply punched, where the material was of the right sort, and with the kind of steel that we can get for boilers in the United States, there is no excuse for it. It may be different in France.

Mr. Henning.—I was talking of Otis steel, which I believe is pretty good.

Colonel Meier.—I think that is a grave mistake to buy steel of any kind by the brand. It should be bought from specifications, and subject to careful tests. I know that unless you test your steel, not only physically but chemically, you are never sure

of what you are getting, no matter what brand is stamped on it.

Mr. McBride.—I was obliged to throw away one set of fire boxes, and they were made of Otis steel.

Mr Barnaby.—I would like to ask Mr. Baker a question. He says that according to late and good practice, butt joints are used with covering plates. He did not just say so, but coming in connection with the discussion of the effects of fire on rivets and lap, I take it that he means that they are used on the fire surface of boilers. I would like to ask if he knows of any case in good practice where a butt joint, with inside and outside covering strips, was placed next to the fire, or even a double-rivetted lap joint. We had one specification that called for a double-rivetted girth seam on an externally fine boiler, but the specifications also called for Hartford insurance. So we submitted it to them, and they instructed us to notify the purchaser that they would refuse to insure the boiler if it was made with a double-rivetted girth seam.

Mr. F. W. Dean.—I am very glad to see a paper on this subject brought before the Society, because it is time to check an evil which has existed for many years, and which seems to be spreading. It is one of the functions of the American Society of Mechanical Engineers to check erroneous ideas and disseminate correct ones, and therefore it should be emphatic on this subject.

In my discussion of this paper I shall chiefly quote a portion of a former paper of mine on this subject before another society.

In the case of water tube-boilers nobody thinks of calling the inside of a tube the heating surface. The practice with this type of boiler is correct, and the discussion is not a criticism of the makers and users of them.

In deciding which surface shall be employed, it is necessary to consider what heating surface really is. I define it as the surface, of whatever kind, in contact with the source of heat, and by source of heat I mean the hot gases evolved by the process of combustion. The tubes are a necessary medium between the gases and the water, and it is they which extract the heat from the source, and merely transfer it in a more or less perfect manner to the water. They represent the water, so to speak. For this reason, viz., that their fire side takes the heat from the

source, their fire side, or inside in fire-tube boilers, should be used in computing heat surface.

In considering this matter, if the tubes stored up heat from the gases and then gave it off to the water, there might be an argument in favor of the outside surface. The capacity of a tube, however, to give its heat to the water is so enormous and so far in excess of its power to take heat from the source, that, as is well known, its own temperature is about that of the water. This is very clearly shown by the behavior of the Serve internally-ribbed tube, for so perfectly does this tube give up its heat to the water that the ribs suffer no harm from overheating.

A further consideration of the Serve tube will assist in making this matter clear. This design adds to the fire surface of the tube, and not to the water surface. If the water surface be considered, a boiler fitted with Serve tubes is rated only equal to one with plain tubes, and yet it has the capacity of a boiler of much greater heating surface. By using the fire surface, the Serve tube is credited with what in effect it possesses, viz., greater heating surface than the plain tube.

Consider also the plain tube pushed to an extreme thinness. The thinner the tube is, the better will it perform its function. If it could be made infinitely thin, a boiler possessing it would have its best qualities, and equal to those of a boiler with a greater number of thicker tubes.

The boiler with the infinitely thin tubes would have its inside and outside surfaces coincident, and would therefore have its heating surface equal to the inside surface of the tubes.

If, now, the outside surfaces of tubes constitute boiler heating surface, this surface can be augmented by increasing the thickness of tubes. This is, however, a means of retarding the flow of heat through the metal of the tube, and, therefore, of virtually decreasing the heating surface instead of increasing it.

These arguments clearly show to the writer that the outside surface is a misrepresentation of the heating surface with fire tubes, and that the thicker the tube the greater the misrepresentation becomes.

William H. Bryan.—While some of us may not agree altogether with Mr. Baker in designating heating surface as the most important characteristic of a steam boiler, we will nevertheless admit that it is of sufficient importance to make it essential

that we define and measure it correctly. Mr. Baker has done the profession an excellent service in calling attention so clearly to the essential differences between the work done by the fire and water sides of boiler tubes. I presume that most engineers have—like myself—given the matter very little thought, and have jumped at the conclusion that the square foot of surface on the water side which transferred the heat from the tubes to the water, was quite as much entitled to be called heating surface as the square foot on the fire side, which absorbed the heat from the furnace gases. If we had stopped to think, however, we would have recalled the gain which is made in ordinary steam or hot water radiators by simply extending the surface by means of pins or other projections, and we would also have remembered the improved results which are secured by the use of the Serve extended boiler tubes and spiral retarders.

In view of the very clear presentation of this matter which has been made by Mr. Baker, it would seem wise to suggest that the Committee on the Revision of the Code for Boiler Trials amend their report in this respect.

Mr. Baker has also done well to emphasize some other facts with which most engineers as a rule are not familiar. One is that the metal plate, if clean, can only be a few degrees warmer than the water in contact with it. Another is that the principal resistance to the absorption of heat by water is its passage from the gases into the metallic plate. Still another is the fact of the relative unimportance of scale in detracting from the boiler's efficiency, and the very serious importance of soot in lowering boiler efficiency.

I cannot agree with Mr. Baker, however, in his views as to the importance of good circulation in a steam boiler. The fact that the more rapidly the water passes over a square foot of heating surface the more heat will be given off by that area, does not seem to me to be open to argument. My own experience in making boiler trials indicates that those boilers in which the circulation is most sluggish invariably require more heating surface per horse-power.

It is refreshing to read Mr. Baker's frank admission that there is no fixed heat-transmitting value for heating surface, and that one square foot in one type of boiler may do twice the work of the same area in another.

*Mr. Baker.**—I believe it may conduce to sound ideas upon the subject under discussion if we come back to the statement of some elementary facts. In my original paper I have simply stated that given a clean heating surface, of ordinary thickness, with water in contact with one side, and the other exposed to hot gases, the temperature of the plate will be very little higher than the temperature of the water.

If the heating surface on the water side is not clean, so that the heat has to pass through scale, mineral incrustation or a coating of grease (all of them poor heat conductors as compared with iron), then unquestionably, the temperature of the plate will be raised more or less, according to the extent to which the flow of heat is obstructed. Again, if the steam cannot freely pass away from the surface as fast as it is generated, and if it accumulates so that steam instead of water is in contact with the surface of the plate, then the temperature of the plate will rapidly rise. Still again, if there is a double thickness of metal for the heat to pass through, as at the lap of a rivetted joint, the flow of heat is obstructed more or less at the joint between the two plates, just as the flow of electricity is obstructed by similar joints, and we shall have an increased temperature of the plate on the fire side. Unquestionably any of these conditions may become so bad as to cause the plate to assume a temperature far above that of the water in the boiler. But, on the other hand, it is one of the purposes of this paper to point out that a moderate obstruction to the transmission of heat from the plate to the water has little effect on the capacity or economy of the boiler. Figures may make this more clear. Suppose with clean heating surface and a free escape for the steam, the temperature is as follows: Water, 300 degrees; fire side of plate, 320 degrees; hot gases passing over plate, 1,000 degrees; difference between gases and plate, 680 degrees. Suppose, now, that either the presence of considerable scale or a film of oil, or interference with the escape of the steam bubbles causes the temperature of the fire side of the plate to rise to 370 degrees. The difference in temperature between the fire side of the plate and the hot gases will then be 630 degrees, or only about seven per cent. less than in the former case. Of course these figures are merely rough estimates of the actual temperatures, but it

* Author's Closure, under the Rules.

will also be seen that they might vary between wide limits without affecting the substantial accuracy of the conclusions reached.

If this simple statement is carefully followed and thoroughly understood, I believe that the correctness of my suggestion, that circulation in the boilers is less important than has been sometimes claimed, will be conceded. It may be well to point out, however, that the illustrations brought forward to prove the value of circulation are not admissible. In the case of the blacksmith's cooling the red-hot iron in water, we have so great a difference of temperature between the iron and the water that a film of steam is formed between the two, if the iron is held still. In steam boilers, however, no such great differences of temperature occur between the iron and the water. The bubbles of steam tear themselves loose as soon as they are formed, and water rushes in to take their place. Mr. Suplee has instanced the stirring of water in the determination of specific heats, etc. This illustration is also not apropos, for the water in all such cases is below the boiling temperature.

It is common knowledge that the greatest temperature strains in boilers occur when steam is being raised. Before the steam bubbles begin to form, circulation is very slow, and although water is in contact with all heating surfaces, the water in some parts of the boiler gets much hotter than that in other parts, causing corresponding variations in the temperature of the plates in different parts of the boiler. When once steam is raised, however, the evidence of temperature strains disappear. The steam bubbles keep the water in constant circulation, so that it is at the same temperature in all parts of the boiler. The fact that evidence of temperature strains in a boiler disappear as soon as steam is raised, seems to be good evidence that the plates in those parts where the fire is hottest are at not much higher temperature than in those parts which are not exposed to the fire at all.

Concerning the temperature of rivet-heads, it should be noted that the heat absorbed by the whole area of the head has to be transmitted through the shank, of much smaller section. It may be of interest to solve an example to see what will be the actual difference in temperature of the surfaces of the opposite heads of an ordinary boiler rivet. Suppose we have a $\frac{3}{4}$-inch rivet uniting two $\frac{5}{8}$-inch plates. The average distance between

the surfaces of the two heads may be taken as about 2 inches. The area of one head exposed to the fire is approximately $2\frac{1}{2}$ square inches. The cross-section of the shank is 0.44 square inches. If we assume that the heat transmission through the plates in the vicinity of the rivet is at the rate of 2,900 British thermal units per square foot per hour, we have (using the coefficient of conductivity of iron already given in the paper.)

Difference of temperature (number of heat units taken up from hot gases per square foot per hour ÷ 473) multiplied by thickness of plate in inches, multiplied by (quotient of area of rivet-head divided by cross-section of shank).

Or, using the figures already found:

$$\frac{2900}{473} \div 2 \div \frac{2\frac{1}{2}}{0.44} = 70 \text{ nearly.}$$

In other words, whatever the temperature of the water side of such a rivet may be, its side exposed to a fire of the intensity assumed, will be 70 degrees hotter. The above computation leaves out of account the conductivity of the plates between the rivet-heads, and also some other elements which would tend to decrease the difference of temperature just found.

Mr. Bird's assertion that a thin film of gas of low temperature is always to be found next the fire surface of a boiler tube is confirmed by my own observations. Where the gases impinge against any part of the heating surface, this film is removed as fast as formed, and the result is a great increase in the rate of heat transmission.

Mr. Dean's excellent discussion has evidently been prepared with fire-tube boilers only in mind. In the case of water-tube boilers, if we suppose a given interior diameter for the tube, it is not true that the thinnest tubes would have the greatest heat-absorbing power. On the contrary, if we compare two water-tube boilers having tubes of the same internal diameter, but different thickness, the one with the thicker tubes would have the greater heating surface and capacity.

Some comparisons have been made in the discussion between the heating surfaces of boilers and those of condensers, steam radiators, etc. It should be carefully kept in mind that the conditions are quite different where a metal surface is interposed between two gases of different temperatures. Here the temperature of the metal will be somewhere near a mean be-

tween the temperatures of the two gases, but will tend toward the temperature of the one which has the greatest heat transmissive power.

In conclusion, since none of those taking part of the discussion have expressed any doubt of the writer's principal proposition, that the surface exposed to the fire is the actual heating surface of a steam boiler, it is to be hoped that this may be adopted as standard practice by the Society, in accordance with the suggestion of Mr. Bryan.

DCCLXXVI.*

EXPERIMENTS ON CAST IRON CYLINDERS.

BY C. H. BENJAMIN, CLEVELAND, OHIO.

(Member of the Society.)

For several years past the writer has been conducting a series of experiments to determine the bursting strength of cast iron cylinders under water pressure. In this connection he wishes to express his acknowledgments to Messrs. Clifford, Hale, Allen and Wright, who at different times carried out the experiments, and by their patient and careful work made it possible to present these results to the public.

The cylinders used were cast by the Taylor & Boggis Foundry Co. of Cleveland, from a special foundry mixture, such as they ordinarily use for water and steam cylinders. The metal showed a fine gray fracture and a surface close and free from holes. The cylinders were cast on end and without the use of chaplets for the cores.

Test pieces cast from the same iron showed a tensile strength of about 24,000 pounds per square inch, and a modulus of rupture of about 35,000 pounds under a transverse load.

It may be noted, however, that the first three cylinders tested (*a*, *b*, and *c* in Table I) were of common foundry iron, having a tensile strength of about 18,000 pounds.

The cylinders were of three sizes, six, nine, and twelve inches internal diameter, and of lengths approximately twice the diameters.

The flanges and heads were made of extra thickness, that the rupture might always occur in the shell of the cylinder. Fig. 146, and Table I, show the proportions and dimensions of the various cylinders tested.

The cylinders are arranged in the table in the order in which they were tested. Those marked *a* to *f* were broken in the

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* Presented at the Niagara Falls meeting (June, 1898), of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

TABLE I.

DIMENSIONS OF CYLINDERS. (See Fig. 146.)

No.	A	B	C	D	E	Depth Counter-bore.	G	H	I	K	No. of Bolts in each Head.
a	12.16	26.05	.70	16.25	...	...	1.07	1.12	1.0	...	24
b	9.16	17.95	.60	13.06	...	...	1.09	.70	1.0	...	16
c	6.09	12.19	.50	10.05	...	...	1.12	.70	1.0	...	8
d	12.45	26 5	.56	16.21	13.25	.12	1.75	1.35	1.5	...	24
e	9.12	19.0	.61	12 96	10.08	.11	1 5	1.25	1.25	...	16
f	6.12	13.0	.65	10.02	7.08	.11	1.25	1.00	1.25	...	8
1	9.58	18⅞	.402	13.33	10 83	⅛	1 3/16	1⅛	1⅜	11¾	16
2	9.375	18⅞	.573	13.13	10.63	⅛	1 3/16	1⅛	1⅜	11¾	16
3	9.13	18⅞	.596	12.88	10.38	⅛	1 3/16	1⅛	1⅜	11¾	16
4	12.53	25¾	.571	16.4	13.34	⅛	1.34	1½	1 5/16	14¾	24
5	12.56	25⅝	.531	16.56	13.56	⅛	1.34	1 9/16	1 5/16	14¾	24
6	12.16	25⅝	.93	16.22	13.41	⅛	1.18	1½	1 5/16	14¾	24

NOTE.—The rough dimensions in this Table are averages from a number of measurements.

winters of 1895–6, and the remaining six during the succeeding winter.

The cylinders were bored in such a way as to insure a practi-

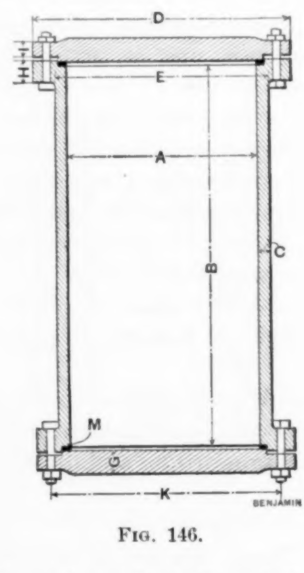

FIG. 146.

cally uniform thickness in each shell, and the flanges were faced and counterbored. Steel bolts, having a tensile strength of about 80,000 pounds per square inch, were used to fasten on the heads,

in such numbers as to give an excess of strength and to prevent leakage.

The arrangement of the apparatus for testing is shown in Fig. 147. A single-acting plunger pump, with a plunger seven-eighths of an inch in diameter, was used for raising the pressure, being connected to the head of the cylinder by extra heavy iron pipe with bronze fittings. The body of the pump and the gland were of bronze and the plunger of machinery steel. For packing, washers of belt leather gave as good results as anything

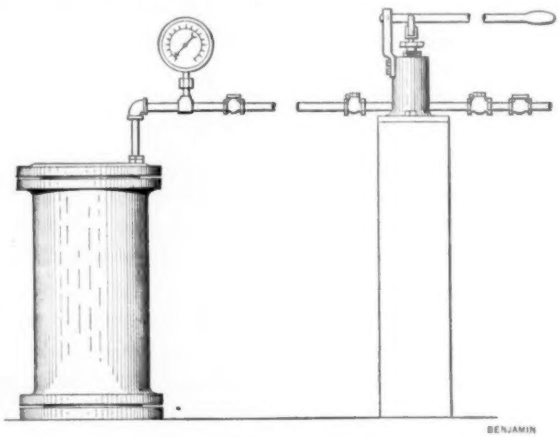

Fig. 147.

which was tried, and but little trouble was experienced with the pump itself.

It was found, however, almost impossible to obtain any check valves which would work satisfactorily at the higher pressures. Numerous types of valves were tried, swing check and drop check, metallic face and rubber face, but they all leaked. Either minute particles of dirt would get under the valves or the slip would be so great as to forbid increase of pressure beyond a certain point.

Following the old adage, "In a multitude of counsellors there is safety," we finally overcame the difficulty in a measure by using two valves on each side of the pump, as shown in Fig. 147.

To determine the pressure we used a Crosby hydrostatic gauge, graduated to 2,000 pounds, located on the pipe close to the cylinder. An attempt was made to use a Bristol recording

gauge, located on the cylinder head, but the jar of the final rupture blotted out all records on the dial.

Before testing, each cylinder was calipered inside at six different points, three measurements being taken in each of two meridian planes at right angles to each other. Gauges, consisting of hard wood sticks, slightly pointed at the ends, were fitted one at each point, and then numbered to correspond.

After the rupture of the cylinder, the increase in diameter was measured by using the same gauges, inserting pieces of hard calendered paper between the ends of the gauges and the shell, and then measuring the thickness of the paper with a micrometer caliper.

The deformations as thus measured were very slight, ranging from .004 to .012 inch, but no law could be determined.

Each cylinder was carefully examined for flaws of any description. If any small blow-holes were found they were filled with lead or tin hammered in, and then the surface was covered with a coating of paraffine. The cylinders were as free from flaws as could be expected.

Of all the difficulties encountered the most serious was that of finding any satisfactory packing for the heads of the cylinders. We tried successively brass wire gauze filled with soap, copper wire, lead wire, soft rubber with graphite, and vulcanized rubber.

The metal gaskets all failed on account of their lack of elasticity. Although tight at the lower pressures, being compressed by the bolts until the soft metal was squeezed into every irregularity of the cast iron surface, they failed to respond when the bolts were stretched by the water pressure, and the water would run through in streams.

This fact is interesting as showing that the initial tension caused by screwing up the nuts has no effect on the tension under pressure when a non-elastic gasket is used.*

The tensile strength of the bolts used in these experiments was much in excess of the strength of the cylinder, and yet, under the comparatively low pressure of 400 pounds to 600 pounds per square inch, the bolts stretched enough to practically relieve the reaction of the gasket. The elastic rubber gaskets failed principally on account of weakness, usually blowing out as the pressure was increased. Vulcanizing by heat made

* See Unwin's *Machine Design*, vol. i., p. 152.

them stronger but less elastic. Acting on the suggestion of Mr. Caldwell, of the Worthington Hydraulic Company, member of the Society, we then counterbored the cylinders to a depth of about one-eighth of an inch, as shown in Fig. 146; fitted a circular projection on the head closely to the counterbore, and introduced at *M* a gasket made of straw-board soaked in boiled linseed oil. The straw-board was cut to fit the counterbore, thoroughly saturated with the oil, and then allowed to stand several hours before being put in position.

Allowing the gasket to harden for twenty-four hours after screwing down and before putting on the water pressure is an additional safeguard.

It is probable that the counterbore had as much to do with the success of this method as the material used for packing, but the gasket must be elastic to insure tightness. In one or two instances where the projection on the head was of slightly less diameter than the counterbore, the packing blew out.

Another serious difficulty was encountered in the presence of minute blow-holes in the shell of the cylinder. Some of these were almost invisible to the naked eye, but as the pressure rose the water would spurt in slender streams to a distance of several feet, in such quantity as to render further increase of pressure impossible. The only remedy in such cases was to peen the interior surface slightly with a round hammer and then coat it with paraffine. Even then the water would ooze from the iron at every pore as if it were in a violent perspiration.

Before beginning each experiment the air was forced out of the cylinder through a small vent at the top. The pressure was then gradually applied until rupture occurred. It was found impracticable to make any measurements of the exterior diameter during the test, the changes being so very minute.

The following is an abbreviated log of the experiments:

Cylinder (a).—Wire gauze packing; leaked at 400 pounds. Substituted copper wire No. 22, A. W. G.; this leaked at 600 pounds. Substituted soft rubber gasket; pressure carried to 800 pounds several times. Leak at blow-hole stopped by peening. On raising pressure to 775 pounds cylinder failed on a circumference just below the upper flange, the crack starting at blow-hole and running each way about 90 degrees.

Cylinder (b).—Gasket of lead fuse wire $\frac{3}{32}$-inch diameter with ends fused together. Leakage at pressure of 450 pounds, and

FIG. 148.

FIG. 149.

the flange cracked. Substituted rubber and graphite packing; leak at crack with pressure of 600 pounds; no further rupture.

Cylinder (*c*).—Rubber and graphite packing inserted, heated to 250 degrees Fahr. by live steam; bolts screwed down and packing left one day to harden. Leaked badly at 600 pounds; renewed packing, but it leaked again at 550 pounds. Flanges showed signs of failure, and experiment was abandoned.

Cylinder (*d*).—Counterbored joint, with gasket of straw-board soaked in linseed oil. Leakage at blow-holes with 700 pounds pressure. Blow-holes peened and coated with paraffine, when pressure was raised to 800 pounds several times. One blow-hole calked on outside; on applying pressure of 700 pounds rupture occurred on longitudinal line through blow-hole. (See Fig. 148.) Several small blow-holes found in line of fracture.

Cylinder (*e*).—(On this and all subsequent cylinders the counterbore and straw-board gasket were used.) Pressure raised gradually to 1,325 pounds, when rupture occurred on circumference under flange. (See Fig. 149.) The crack began at point marked × in figure, where there were several small blow-holes.

Cylinder (*f*).—Pressure raised gradually to about 2,500 pounds (above graduation of gauge), when cylinder failed in same manner as preceding one; cylinder leaking badly at time of rupture.

Cylinder No. 1.—Broke at 600 pounds on a longitudinal line along a row of blow-holes, the crack starting at the mark × in cut. (See Fig. 150.)

Cylinder No. 2.—Broke at 1,050 pounds around a circumference just under flange, the crack beginning at point marked × in cut. (See Fig. 151.) Fracture very clean.

Cylinder No. 3.—Broke at 975 pounds in the same manner as No. 2, the crack beginning at the point marked × in Fig. 152, where there was a slight flaw. Fracture clean, as shown in the figure.

Cylinder No. 4.—A number of small blow-holes near the centre of shell (shown by arrow in Fig. 153) caused considerable trouble by leakage, and had to be calked inside and out. Rupture finally occurred at 700 pounds pressure along a longitudinal line, as shown in the figure.

Cylinder No. 5.—Rupture occurred at 875 pounds, a crack starting under the flange, running part way around and then up through flange and head.

Fig. 150.

Fig. 151.

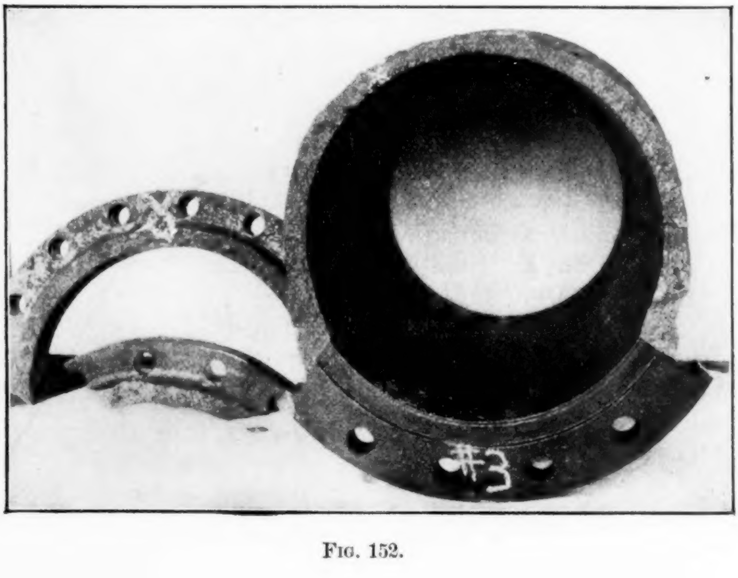

Fig. 152.

Cylinder No. 6.—At 475 pounds pressure the bottom head broke, as shown in Fig. 154. On renewing this and raising pressure to 900 pounds, the top head failed in the same manner. These heads had been used for several cylinders, and were probably weakened. The test was abandoned at this point for lack of time.

Great pains were taken in casting these cylinders, and they may be considered good examples of cast iron cylinders as made for engine or pump work. The blow-holes mentioned were most

FIG. 153.

of them very minute, and under ordinary circumstances would have remained unnoticed.

Before summarizing the results of these experiments we will notice some of the formulas which have been proposed for steam engine cylinders of cast iron.

Let d = diameter of bore in inches.

p = pressure in pounds per square inch.

t = thickness of shell in inches.

s = tensile strength in pounds per square inch.

The ordinary formulas for thin shells are :

For stress around circumference:

$$S = \frac{pd}{2t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For stress along element of cylinder:

$$S = \frac{pd}{4t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Van Buren's formula for steam cylinders is:

$$^{*}.0001\,pd + .15\,\sqrt{d} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

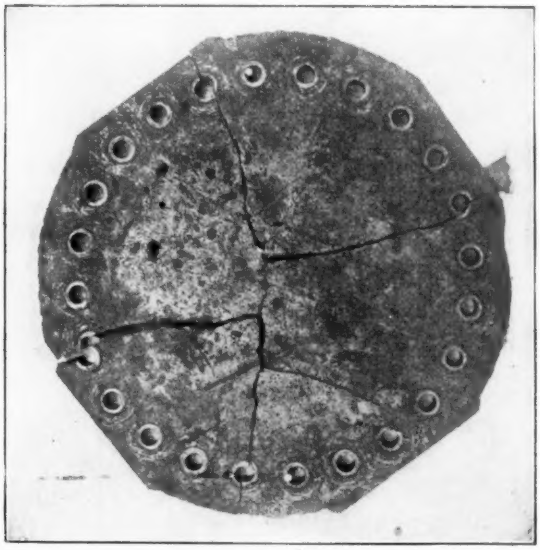

FIG. 154.

A formula which the writer has developed in his "Notes on Machine Design" is somewhat similar to Van Buren's.

Let s' = tangential stress due to internal pressure; then by equation

$$(1) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad s' = \frac{pd}{2t}.$$

Let s'' be an additional tensile stress due to distortion of the circular section at any weak point.

Then if we regard one-half of the circular section as a beam

* See Whitham's *Steam Engine Design*, p. 27.

fixed at A and B (Fig. 155), and assume the maximum bending moment as at C, some weak point, the tensile stress on the outer fibres at C due to the bending will be proportional to $\frac{pd^2}{t^2}$ by the laws of flexure, or:

$$s'' = \frac{cpd^2}{t^2},$$

where c is some unknown constant.

The total tensile stress at C will then be:

$$S = s' + s'' = \frac{pd}{2t} + \frac{cpd^2}{t^2}.$$

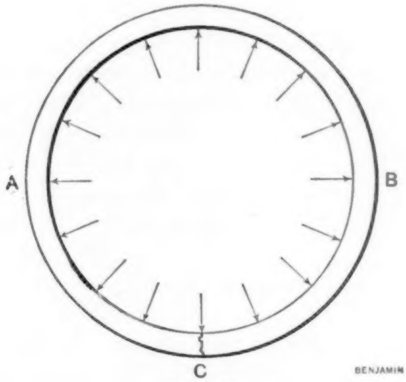

FIG. 155.

Solving for c:

$$c = \frac{st^2}{pd^2} - \frac{t}{2d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

Solving for t:

$$t = \frac{pd}{4S} + \sqrt{\frac{cpd^2}{S} + \frac{p^2d^2}{16S^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

a form which reduces to that of equation (1) when $c = o$.

An examination of several engine cylinders of standard manufacture shows values of c ranging from .03 to .10, with an average value:

$$c = .06.$$

The formula proposed by Professor Barr, in his recent paper on "Current Practice in Engine Proportions," * as representing

* *Transactions*, A. S. M. E., vol. xviii., p. 741.

the average practice among builders of low speed engines, is:

$$t = .05d + .3 \text{ inch.} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

In Table II. are assembled the results of the various experiments for comparison. The values of S by formula (1) are calculated for each cylinder, and by formula (2) for all those which failed on a circumference. It will be noticed that six out of nine cylinders failed in the latter way.

TABLE II.

No.	Diam. d	Pressure. p	Thick. t	Line of Failure.	Formulas Used. 1 $S=\frac{pd}{2t}$	2 $S=\frac{pd}{4t}$	a $c=$	Remarks.
a	12.16	800	.70	Circum.	6,940	3,470	.046	Strength of test bar, 18,000 lbs.
d	12.45	700	.56	Longi.	7,780	...	.047	Strength of test bar, 24,000 lbs.
e	9.12	1,325	.61	Circum.	9,900	4,950	.048	" " "
f	6.12	2,500	.65	Circum.	11,800	5,900	.055	" " "
1	9.58	600	.402	Longi.	7,150	...	.049	" " "
2	9.375	1,050	.573	Circum.	8,590	4,300	·055	" " "
3	9.13	975	.596	Circum.	7,470	3,740	.072	" " "
4	12.53	700	.571	Longi.	7,680	...	.048	" " "
5	12.56	875	.521	Circum.	10,350	5,180	.028	" " "

Average of $c = .05$.

This appears to be due to two causes. In the first place, the influence of the flanges extended to the centre of the cylinder, stiffening the shell and preventing the splitting which would otherwise have occurred.

In the second place, the fact that the flanges were thicker than the shell caused a zone of weakness near the flange due to shrinkage in cooling, and the presence of what founders call "a hot spot."

In some of the cylinders this was quite apparent, the metal being porous and spongy near this point. It was found impossible to reduce the thickness of the flanges without making them too weak for the pressure [notice experiments (b) and (c)].

This would indicate the desirability of making flanges of the same thickness as the shell and reinforcing them by brackets.

It will also be noticed that the stress per square inch by formula (1) is only about one-third the tensile strength of the material as shown by test bar. This is partly due to the effect of distortion or bending from lack of uniformity in the metal

and its thickness, but principally due to the presence of minute flaws and blow-holes. This is only another illustration of the fact that the strength of a test bar is no index of the strength of a casting.

The stresses figured from formula (2) in the cases where the failure was on a circumference, are from one-fifth to one-sixth the tensile strength of the test bar.

The strength of a chain is the strength of the weakest link; and when the tensile stress exceeded the strength of the metal near some blow-hole or "hot spot," tearing began there and gradually extended around the circumference.

Values of c as given by equation (a) have been calculated for each cylinder, and agree very well except in numbers 3 and 5.

To the criticism that most of the cylinders did not fail by splitting, and that therefore formulas (a) and (4) are not applicable, the answer would be that the chances of failure in the two directions seem about equal, and consequently we may regard each cylinder as about to fail by splitting under the final pressure.

If we substitute the average value of $c = .05$ and a safe value of $s = 2{,}000$, formula (4) reduces to:

$$t = \frac{pd}{8{,}000} + \frac{d}{200}\sqrt{p + \frac{p^2}{1{,}600}} \quad . \quad . \quad . \quad . \quad (6)$$

CONCLUSIONS.

The conclusions which might fairly be drawn from these experiments would seem to be:

1. That cast iron cylinders of the form ordinarily used for engines, when subjected to internal pressure are quite as likely to fail by tearing on a circumference as by splitting.

2. That by reason of local weaknesses and distortions the cylinder may fail when the stress, as calculated by the ordinary formula for thin shells, is only about one-third of the strength shown by a test bar.

3. That the principal cause of weakness is the sponginess of metal due to uneven cooling; that to insure good castings the flanges should not be materially thicker than the shell; the cylinders should be cast on end, and suitable risers provided for the escape of dirt and gas and to secure uniform cooling.

4. That one proof test will give more information than a deal of computation.

DISCUSSION.

Prof. Thomas H. Gray.—The question of packing, to which Professor Benjamin refers, is one which has given a great deal of difficulty to other experimenters. I may say that one very satisfactory way of packing a cylinder for internal pressure, which applies not only to the case of a steam engine cylinder which is practically round and smooth, but applies also to one which is out of round, is to place inside the head a cup-leather made of sole leather, giving sufficient cupping to give a covering to the end of the cylinder. If that cup of leather be properly put in, it becomes tighter the higher the pressure. The cup-leather will hold a pressure similar to that used in Professor Benjamin's experiments, even when the heads are held by bolts which pass from end to end of the cylinder, instead of into the flanges, so that the stretch of the bolts gives a considerable opening at the end after the pressure is put on. We have a perfectly free cylinder with a tight joint, the flexibility of the leather being such that no increase of strength is produced by the packing. I only suggest this as a means of overcoming the difficulty. I believe the means adopted for steam engine cylinders is satisfactory. My idea was that Mr. Benjamin wanted to test his cylinders under ordinary working conditions. There is one point in connection with the breaking of the flanges that should not be overlooked. The explanation given is that the flanges break off because of unequal stresses in the material, due to cooling. There is, however, a very important element in regard to the effect of end pressures when we bolt the head to a flange, and that is the cross-breaking stress that is brought upon the material at the outside in the neck of the flange. We are apt to have the flange crack around the neck, which, of course, gives a tendency to break off the flange in the first place; but just the direction in which that crack may run is pretty much a matter of accident. I think in all probability a good deal of the trouble coming from that difficulty would be overcome if the flanges were made about the same thickness as the cylinder, properly filleted out so as to give a round corner, and then a sufficient number of thin brackets brought down as Professor Benjamin has spoken of. I think that would be very satisfactory for test purposes, but a great many steam cylinders do not have those brackets.

Mr. H. H. Suplee.—I think one point which Professor Benjamin made in the close of his paper, that the work should be tested as nearly as possible under the conditions of use, should call attention to the fact that these are really short sections of pipe and do not represent steam engine cylinders at all. If the presence of the slight excess of metal in the flange effects the result, it seems to me that the presence of a large mass of iron, such as is always included in the steam chests on one side, would have a still more marked effect. If you take up the locomotive cylinders, where half of the front of the engine is cast in one piece with the cylinder, the mere pressure within does not give us the true condition of affairs at all. I believe also that it is the practice in locomotive construction to make the flanges very much thicker on the cylinder for the purpose of causing any break which may take place due to water or a nut coming off, to occur in the head, the place where it is most easily replaced, and not to break off the flange from the cylinder and destroy the whole front of the engine. In that case, of course, the question of bending and fracture, as shown, for instance, in Fig. 151, would be very serious. But I think that the presence of a mass of metal on the side in the shape of a steam chest in the case of a locomotive, or the ports and valve seats in the case of a Corliss cylinder, is such as almost entirely to change the conditions and make these tests hardly applicable to the conditions of a working engine.

Mr. William Kent.—Professor Benjamin's paper is a valuable contribution to our knowledge of the subject of the bursting strength of cast iron cylinders. It furnishes new confirmation of the law that "it is the unexpected which happens" when we are dealing with cast iron. The unexpected result in this case is that if cast iron, which in a test bar shows a tensile strength of 24,000 pounds per square inch, be cast in the form of cylinders, which are bored out to diameters of 6 to 12½ inches, with thicknesses from 0.40 to 0.65 inch, they will burst under internal pressures which correspond to tensile stresses of from 3,740 to 11,800 pounds per square inch, and that only three out of eight cylinders will break in the way they would be expected to break; that is, by longitudinal splitting.

While Professor Benjamin's experiments are of value in calling attention to this peculiarity of cast iron cylinders, they do not seem to form a sufficient basis for a formula for dimensioning

the cylinders of steam engines. The cylinders he tested had a maximum diameter of 12.56 inches, and a maximum thickness of 0.65 inch. It is scarcely safe to predict from the behavior of these cylinders what would be the probable strength of larger cylinders.

I fail to see a good reason for constructing the formula (4) in the assumption that there is a "bending movement as at C, some weak point," and for the derivation of the average value of C in that formula, 0.6, from a range of 0.3 to 0.10 obtained from an examination of several engine cylinders of standard manufacturers. If the formula itself is derived from a logical basis, it would seem that the constant C should be determined from actual bursting tests of several engine cylinders (not mere examinations), and such tests it does not appear that Professor Benjamin has made.

Let us apply Professor Benjamin's formula (6) to the case of three steam engine cylinders, 10, 30, and 50 inches diameter, for a pressure of 100 pounds per square inch.

The formula is:

$$t = \frac{pd}{8{,}000} + \frac{d}{200}\sqrt{p + \frac{p^2}{1{,}600}}.$$

For the three cylinders the term $\frac{pd}{8{,}000}$ is respectively:

0.125, 0.375, 0.625 inches,

and the term,

$\frac{d}{200}\sqrt{p + \frac{p^2}{1{,}600}}$, 0.515, 1.03, 2,575 inches;

adding we have,

$t = 0.64$, 1.405, 3.20 inches.

Professor Barr's formula, from average practice, $t = 0.05d + 0.3$ inch, gives:

$t = 0.80$ 1.30 2.80.

In my *Mechanical Engineers' Pocket Book*, p. 794, the thicknesses of these three cylinders, calculated from the average figures given by eleven different published formulas, are:

$t = 0.76$ 1.48 2.26.

My approximate formula, made to fit these averages, is

$t = 0.0004\, dp + 0.3$ inch, and the thicknesses calculated from this formula are:

$$t = 0.70 \qquad 1.50 \qquad 2.30.$$

Professor Barr's formula agrees exactly with mine if, in the latter, p is taken at 125 pounds per square inch.

The eleven formulas above mentioned give the following ranges of thicknesses:

Minimum . . .	0.33	0.99	1.56.
Maximum . . .	1.13	2.00	3.00.

Professor Benjamin's formula (6) gives for the 50-inch cylinder a thickness of 3.20 inches, which is greater than that given by any one of the eleven formulas, while his figure for the 10-inch cylinder is much smaller than is given either by Professor Barr's formula or by my own. For these reasons it does not seem advisable that Professor Benjamin's formula (6) should be adopted as a working formula for dimensioning engine cylinders.

Mr. Charles Whiting Baker. — Professor Benjamin's paper raises some interesting questions relating to an entirely different industry, the manufacture of cast iron pipe. It will be noticed that in several of the cylinders tested, leakage occurred through minute blow-holes, sufficient to interrupt the test until the holes were stopped by peening or filling with soft metal. Now, if cylinders like these have such blow-holes, do not similar blow-holes exist in cast iron water pipe? These cylinders were cast, it is fair to presume, with far more care than is exercised in any pipe foundry. The thickness of the metal was as great as is found in cast-iron pipe of 10 to 30 inches diameter. If these cylinders had blow-holes we know of no reason to suppose that cast iron pipes do not have similar blow-holes. On the other hand, we know that very few lengths of cast iron pipe have to be rejected for leaks under the hydraulic test, and leaks in water mains after they are placed in the ground, which are found to be due to holes through the pipe itself, are quite infrequent. It is interesting to inquire the reason for this, and the most probable reasons appear to us as follows: In the first place, the cylinder castings have the skin of the metal removed on the interior of the metal. It is quite likely that the skin of the metal in a cast iron pipe is more solid than its interior. In the second place, all cast iron pipe is dipped in a bath of pro-

tecting coating, which not only covers the surface of the metal on both sides, but runs into and fills any small cavities and blow-holes that may exist. Further, the coating in any such blow-holes is in a large measure protected from the influences which tend to destroy or remove the coating on the surface of the pipe, and will probably continue to do its duty in keeping the pipe tight even when much of the interior coating is worn off. Probably very few water-works engineers have ever reflected that water pipe is dipped in a protective coating to make it tight under pressure, as well as to preserve it from rust; but there seems good reason to believe that this is the case.

*Mr. Benjamin.**—The simple cylinder with flat heads bolted to flanges was adopted as representing the conditions obtaining in the cylinder of a common slide-valve engine when the steam chest, being only on one side and with walls of the same thickness as the cylinder, has no appreciable effect on the strength of the casting.

I agree with Mr. Suplee that the conditions are entirely different in the locomotive and the Corliss cylinder. How the peculiarities of design in such cylinders would affect the strength is merely a matter of guesswork at present, and it is hoped that these elementary experiments may be followed by others to settle these other points. The experiments cited in the paper are only a beginning, and hope next year to test cylinders with the flanges of the same thickness as the walls, and strengthened by brackets.

Professor's Gray's remarks with regard to the bending moment under the flange are much to the point, but I still think that the beginning and the direction of fracture are mostly dependent on the presence of accidental flaws in the metal.

The formula proposed in the paper, while it has its "weak points" like the cylinder to which it is applied, is quite as logical as Gordon's formula for columns or even Hooke's law itself.

That there is liable to be bending at any point where the metal is thinner or weaker than elsewhere seems obvious, and that this will add to the tensile stress on either inside or outside seems equally obvious. A determination of values of C from existing practice was rather to show the variations in that practice than to establish a proper value of the constant.

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* Author's closure, under the Rules.

I entirely agree with Mr. Kent that the value of C should be determined ultimately by experiment, and that is just what we are beginning to do. The uniformity of the values of C given in Table II. is all that could be expected from so limited a number of experiments.

If formula 4 is logical and should be confirmed by further experiment, the comparison made by Mr. Kent would only show some of the eccentricities of contemporary engine design.

A moment's study of Professor Barr's diagram on p. 741 of vol. xviii. of the *Transactions* of this Society will convince one that the formula would need to be elastic which should cover the curves there shown.

Whether formula 4 will apply as well to large cylinders as it does to small is a matter for further experiment; but it is to be remembered that any formula is but a rough guide in the presence of new conditions, and a poor substitute for the "critical instinct."

DCCLXXVII.*

PATENTS.

BY JAMES W. SEE, HAMILTON, OHIO.
(Member of the Society.)

THE special law books deal thoroughly with the subject of patents, but such books are too voluminous for use as working tools by the members of the Society, many of whom have to do largely with patent matters. Again, unfortunately, there are certain matters connected with patents which are generally ignored by the text-book writers, on the professional theory that they involve truisms not calling for discussion. And it is on these ignored matters that engineers and manufacturers, constantly in contact with the subject of patents, seem often to go astray. For instance, it is astonishing how often the intelligent manufacturer expresses an anxiety to get a patent on some new product so that he can begin its manufacture without danger of infringing upon other patents. The following remarks are designed to avoid discussion of controversial points; to be generally on the safer side in questionable matters; to deal only with questions on which inventive mechanics and manufacturers ought to be posted for purposes of every-day work with inventions; and to treat the subjects from the practical view of the shop, experimental room, and office. The particular points herein considered may be briefed as follows:

Preliminary examinations are of merit in certain cases only.
Caveats are generally misunderstood.
Hurried applications are generally unwise.
Inventions are not easily stolen.
The first meritorious inventor prevails.
A patent is not a license.
Joint invention is often misunderstood.
Employers' rights are often misunderstood.
Change of purpose is not patentable.
Combination claims are good claims.

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* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Vol. XIX. of the *Transactions*.

Aggregation is not invention.
Specific claims should supplement generic claims.
Sub-combinations are patentable.
The doctrine of mechanical equivalents inures to pioneers.
Modifications should not generally be set forth in patents.
Divisional applications are wise and often necessary.
A superior patent solicitor is not necessarily the best for all classes of cases.
The contingent fee system is generally but not necessarily bad.
Infringement cannot always be determined from the face of the patent.
The Government cannot insure the validity of a patent.
Patent copies and digests are useful tools.
Foreign patents should be contemplated with caution.

Preliminary Examinations.

If an application is filed for a patent it may become rejected on flat references which, if known in advance, might save the entire expense of the application. Some months generally elapse between the filing of the application and the reaching of it for official examination, the inventor during this time being in doubt as to where he stands and as to the advisability of spending money in promoting the invention. Hence the idea of a preliminary examination into the novelty of the invention. In some lines of invention it is possible to look up all of the patents in that line, and thus get a general notion of the prospects. If a flat anticipation is encountered then the matter may be dropped. The expense of the preliminary examination is but a few dollars, and may be the means of saving the cost of an application and of promptly showing that no further hopes need be had. But preliminary examinations are of respectable value only when they do succeed in bringing out such flat anticipations. If they do not develop anticipating matter it does not follow that the exhaustive official examination will not do so. No cheap preliminary examination can extend beyond United States patents, thus leaving foreign patents and literature and pending applications entirely unsearched, nor can preliminary examinations contemplate with any satisfactory degree of certainty the position which may be taken by the officials as regards questions, aside from novelty, of aggregation, non-invention, etc. Preliminary examinations can be made only where the invention can be searched for in well-defined classes. Where the invention is liable to be buried in non-cognate classes, or in an enormous number of classes, no reliable cheap examination can be made. Many cases occur in which it is impossible to

say that anticipations of the invention should be looked for in certain classes of patents, and not elsewhere. For instance, a given detail of mechanism, invented with special reference to a steam-engine governor, might be found in connection with unthought-of textile machinery, or a cord guiding device for a steam-engine indicator might be found fully anticipated in some patent for the rigging of ships. By "cheap" preliminary examination, I mean an examination whose low cost will justify its being made for the purpose of possibly saving the expense of an application. Even where an invention might be searched for in well-defined classes, slips may occur by reason of broken sets of patents in the portfolios of the Patent Office. It has often happened that a conscientious search through a given sub-class in the Patent Office has indicated a clear field, and that the subsequent official examination resulted in a flat reference, which belonged in that sub-class and belonged nowhere else. In other words this reference should have been found during the preliminary examination. But it has developed that the portfolio was incomplete. It is the aim of the Patent Office to keep them complete and to surround them with reasonable safeguards, but rascally searchers, with the desire to save the trifling cost of a copy of a patent, are able to abstract copies and leave the portfolios incomplete. These portfolios, altogether, contain over a half million patents, and there seems no reasonable way to insure their constant completeness. With a view to possibly saving the cost of an application, and with a view to prompt information on which to found hope or despair, it is advisable to make preliminary examination in case the invention will fit into fairly defined classes of patents, but not otherwise.

Caveats.

Many inventors seem to have a notion that a caveat is a provisional sort of a patent; that it constitutes title to property in inventions; and that it is a quick and cheap method for securing temporary protection. This is all wrong, for caveats fulfil none of these conditions. When an inventor contemplates the production of an invention along a given line, and where he fears other inventors might have or get, properly or improperly, similar ideas, and beat him in the race of diligence in completing the invention, he may make up a description of his incom-

plete invention, observing proper formalities, and lodge the same in the secret archives of the Patent Office on payment of a fee. The caveat term is one year, and may be renewed from year to year by the payment of annual fees. No patent will ever be granted to him as a result of the caveat. The filing of the caveat is no evidence that the caveated invention is new or patentable. No examination is made by the Patent Office into the novelty or patentability of the subject matter of the caveat. The caveat is utterly without effect as regards the rights of the public or of other inventors. The sole purpose of the caveat is to secure notice to the caveator in case a competing inventor applies for a patent, thus giving the caveator an opportunity to complete his invention and file his application and establish such rights as he may be entitled to. If during the caveat period an application is filed by a stranger seeking a patent on the subject matter of the caveat, such application will be suspended, and the caveator will be given notice, and will be given three months in which to file a proper application for a patent, whereupon interference proceedings will be had to determine the question of priority. The caveat will not comprehend competing applications already on file before the caveat. It is advisable to have nothing to do with caveats, but to accomplish the caveat purposes by means of an application for a patent, for it is only in rare cases that matter can be described in a caveat which cannot be put into satisfactory provisional form for the purposes of a formal application. The preparation and filing of a caveat costs nearly as much as an application; its period is but one year without additional fees; it provokes no official examination, and therefore gives no notion of the prior state of the art, and it can never eventuate in a patent. A formal application, made for mere caveat purposes, costs but little more than the caveat; it provokes an official examination into the state of the art, and thus serves to indicate whether or not its subject matter is new and patentable; it brings about the same notice and interference proceedings with any competing applicant, regardless of whether the competing application is earlier or later than the application in question; the application may be caused to eventuate in a patent if the matter is patentable and in satisfactory form; the application can be delayed within reasonable limits while the invention is being perfected; or in the end the application may be abandoned in favor of a later

application for the invention in its more perfected form. An application has a further advantage in the fact that in case of interference proceedings it may give the applicant the benefit of the senior date of filing, and thus throw burden of opening proofs upon his competitor, while in the case of an application following notice under a caveat the caveator's application is bound to be of junior date. Briefly, a caveat does nothing that an application does not do, and an application does much that a caveat cannot do.

Hurried Applications.

Many inventors produce an invention and then seek a patent without delay, the result often being that the invention is patented in half-baked condition and must be followed up by later patents on more perfected forms, and that commercial experience may prove the invention a failure; and often the premature application results in such exposures as will preclude the later getting of patents with claims of adequate scope. The only advantage of the prompt application is that it enables an inventor to ascertain whether or not he is working in an old field. An application filed merely for the purpose of ascertaining the state of the prior art had often better be allowed to slumber while the invention is being mechanically and commercially developed. An inventor loses none of his rights by delaying his application for a patent. The law gives the inventor a period not exceeding two years in which to publicly exploit his invention before applying for his patent. He may sell the patented invention by the thousands without affecting his rights to the patent, so long as he applies for it within two years from its first publication by print or sale. During this period he may test the market and may improve his invention, and when he applies for his patent he may cover the invention in an approved form. Furthermore, the effect of the delay has been to give a later date to the patent, thus prolonging the date of its expiration nearly two years. If infringements develop during the period in question, then it may become advisable to avoid further delay in applying for the patent.

An exception should be noted regarding this matter of delaying the application. There is a class of inventions which might be called bubble inventions, or those which will sell for a short time only. Toys and advertising devices often come under this

head. Such an invention, if put upon the market without patent, might provoke enterprising competitors having superior facilities and capable of getting all of the cream off of the business before the patent could be procured. Such inventions should be patented before they are exploited. Briefly, get the patent as quickly as possible if the commercial life of the invention is likely to be a short one; but, otherwise, delay the application, within the two-year period of exploitation, with a view to having the patent embody developed improvements, and with a view to prolonging the protected period.

Stealing Inventions.

Ideas can be stolen from the originator. But there is no excuse for inventions being stolen. An idea is not an invention, but is merely a hopeful conception of a possibility. The invention is the possibility reduced to form. Many men have ideas which are mere visions and which never can be given form by anybody; other men have ideas which they would be incapable of reducing to form themselves, but which could be reduced to form by others if the idea was disclosed. The mere hint or idea is of no benefit to the public, and is not the thing which the law seeks to reward. The useful invention is the thing which is recognized. It is quite common, when a meritorious inventor has gotten his patent, to hear numerous men say, "He stole that from me," when the fact was there was nothing to steal, no invention but merely an idea. As an example: Let *A*, in talking to *B*, suggest the high desirability of a balloon which could go to the moon, *B* never having thought of the subject before, and *A* never thinking of it again. In a year or two, *B*, having wrestled with the subject, discloses and patents a system by which a balloon carries certain chemical charges acting in conjunction with atmospheric elements and rendering it possible to recharge the balloon with gas indefinitely so that it can go to the moon. *A* will solemnly assert that *B* stole this invention from him, when the fact was that there was no invention until *B* made it. Even if *A* was able to make the invention, he showed no disposition to do so. The law rewards him who accomplishes something instead of him who merely suggests the desirability of a certain accomplishment. Regardless of who first conceives of the desirability of an invention, he who actually makes the

invention first is the one entitled to a reward. If the inventor of an idea does not wish to be beaten out of the reward, let him keep the idea secret and act upon it; and if a competitor appears to exist, diligence must be shown in order to prevail against the competitor. The idea of an invention, followed by occasional and half-hearted attempts to reduce the thing to the form of an invention, will not prevail against the meritorious inventor who, though later to conceive, or even borrowing the idea, was the first to reach the goal of practical accomplishment which benefits the world.

But if an inventor has gone further than the idea, and has developed it into an invention, then the only way he can lose his rights is to keep it secret, so that he cannot prove that he had any rights. The originator of an invention who has reduced it to an actual useful invention, and can prove that fact, cannot be deprived of his rights. A competing inventor may meet him in the patent office with an application, or the competing inventor may actually get his patent before the meritorious inventor has applied for his patent, but if the facts are susceptible of proof, the meritorious inventor, after proper interference proceedings, will be adjudged his rights and will get his patent, and the patent of his competitor will be practically void.

Briefly, then, keep ideas of invention secret, for fear a more enterprising man acting on that idea may be the first to actually evolve an invention from it; be not so secret as to exclude knowledge from friends who may be needed to make proof of dates and diligence; be diligent in reducing an idea to a practical invention; when the idea is reduced to a practical invention, avoid secrecy, so as to have ample proof of the fact.

First Inventor.

In conflicts between interfering inventors, both seeking a patent on the same invention, he is the first inventor and entitled to the patent who has best done his duty by the public whose reward he seeks. This duty cannot be measured by any fixed standard, and each case must stand largely on its own merit. If an inventor has been diligent in pushing his conceived invention forward into a condition where it is in a position to advance the useful arts, he is not to be deprived of his reward

by dilatory earlier conceivers, who have gone only so far as mere disclosures or sketches or drawings, or abandoned experiments or abandoned caveats. Priority of conception must be coupled with reasonable diligence. If there is no negligence on the part of the first inventor, the second inventor, though the first to reduce the invention to practice, will not prevail. An application for a patent is construed in law to be a reduction to practice. The first inventor is, therefore, either he who first conceives the invention and follows it up with reasonable diligence, or he who conceives later than a negligent inventor and first reduces the invention to practice.

A Patent is not a License.

Many manufacturers labor under the mistaken impression that if they patent some new machine they are therefore free from the possibility of infringing on other patents. It is astonishing how common this error is, and how many manufacturers are in a hurry to get a patent, in order that they "may make the thing without danger from others." An original and meritorious patented invention may be dominated by some previous patent. A patented invention may be improved by a subsequent inventor, and most inventions are improved from time to time, but the improver acquires no rights under the fundamental patent by reason of having improved the fundamental invention. You cannot put your saddle on another man's horse, and thereby claim the right to ride that horse.

And the inventor of the improvement, having exercised the talent of invention and having advanced the useful arts, is just as much entitled to a patent for his improvement as the fundamental inventor was for his fundamental invention. It might be asked if it was not folly to patent an improvement which could not be used in view of a dominating patent. The answer is that improvement patents are often as valuable as fundamental patents, by reason of their expanding the market for the fundamental invention by increasing its capacity or lessening its cost. It is true that the owner of the fundamental patent may be the only possible customer for the improvement patent, but it often happens that the improvement is important or even essential to the financial success of the fundamental invention. Again, it may develop, in course of time, that the fundamental

patent is invalid for some reason, and in any event the fundamental patent will expire while the improvement patent is in force.

Joint Inventors.

Where an invention is the result of the joint efforts of two or more parties, all the inventors must join in applying for the patent. Where an invention is the result of the effort of a single inventor he should not join with him anyone who has merely exercised mechanical skill in carrying out his instructions in developing the invention, or anyone who has joined him in a financial or proprietary capacity. In case the skilled mechanic has been called on by the inventor in developing his invention, and a doubt arises as to whether or not the skilled mechanic has or has not exercised some act of invention, doubts should be resolved in favor of the skilled mechanic having done so, and he should join in the application, the fundamental inventor securing himself by proper preliminary contract with the mechanic, and by deed of assignment under the application. Questions of personal pride in connection with patents should always give way to legal considerations of the validity of patents.

Employers' Rights.

An invention, to be patented, must be applied for by the actual inventor, and in the absence of acts constituting a transfer, the patent, and all legal ownership in it, and all rights under it, go exclusively to the inventor. In the absence of express or implied contract a mere employer of the inventor has no rights under the patent. Only contracts or assignments give to the employer, or to anyone else, a license or a partial or entire ownership in the patent. The equity of this may be appreciated by examples. A journeyman carpenter invents an improvement in chronometer escapements and patents it. The man who owns the carpenter shop has no shadow of claim on or under this patent. Again, the carpenter invents and patents an improvement in jack-planes. The shop-owner has no rights in or under the patent. Again, the carpenter invents an improvement in window-frames, and the shop-owner has no rights. He has no right even to make the patented window-frame without license. The shop-owner, in merely employing the carpenter, acquires no rights to the carpenter's patented inventions.

But there are cases in which an implied license would go to the shop-owner. For instance, if the carpenter was employed on the mutual understanding that he was particularly ingenious in devising carpenter work, and capable of improving upon the products of the shop; and if in the course of his work he devised a new and patentable window-frame, and developed it in connection with his employment and at the expense of his employer; and if the new frames were made by the employer without protest from the carpenter, the carpenter could, of course, patent the new frame, but he could not oust the employer in his right to continue making the invention, for it would be held that the employer had acquired an implied license.

If he could not use it, then he would not be getting the very advantage for which he employed this particular carpenter; and if he did get that right, he would be getting all that he employed the carpenter for, and that right would not be at all lessened by the fact that the carpenter had a patent under which he could license other people. The patent does not constitute the right to make or use or sell, for such right is enjoyed without a patent. The patent constitutes the "exclusive" right to make, sell, or use, and this the shop-owner does not get unless he specially bargains for it. Implied licenses stand on delicate ground, and where men employ people of ingenious talent, with the understanding that the results of such talent developed during the employment shall inure to the benefit of the employer, there is only one safeguard, and that is to found the employment on a contract unmistakably setting forth the understanding.

New Purpose.

If an invention is old, it is old regardless of any new purpose to which it is put. It is no invention to put a machine to a new use. If an inventor contrives a meritorious machine for the production of coins or medals, his invention is lacking in novelty if it should appear that such a machine had before been designed as a soap press, and this fact is not altered by any merely structural or formal difference, such as difference in power or strength, due to the difference in duty. The invention resides in the machine and not in the use of it. If the soap press is covered by an existing patent, that patent is in-

fringed by a machine embodying that invention, regardless of whether the infringing machine be used for pressing soap or silver. And it is no invention to discover some new capacity in an old invention. An inventor is entitled to all the capacities of his invention.

Combination Claims.

Many people have an erroneous notion regarding patent claims, and consider the expression "combination" as an element of weakness. The fact is, that all mechanical claims that are good for anything are combination claims. No claim for an individual mechanical element has come under my notice for many years, and I doubt if a new mechanical element has been lately invented. All claims resolve themselves into combinations, whether so expressed or not. Combination does not necessarily imply separateness of elements. The improved carpet tack is after all but a peculiar combination of body and head and barbs. The erroneous public contempt for combination claims is based upon the legal maxim, that if you break the combination you avoid the claim and escape infringement, and this legal maxim should be well understood in formulating the claims. If the claim calls for five elements and the competitor can omit one of the elements, he escapes infringement. Therefore, the claim is good only when it recites no elements which are not essential. Many inventors labor under the delusion that a claim is strong in proportion to the extent of its array of elements. The exact opposite is the truth, and that claim is the strongest which recites the fewest number of elements. It is the duty of the inventor to analyze his invention and know what is and what is not essential to its realization. It is the duty of the patent solicitor to sift out the essential from the non-essential, and to draft claims covering broad combinations involving only essential elements. Sometimes the inventor will help him in this matter, but quite as often he will, through ignorance, hinder him and combat him. The invention having been carefully analyzed and reduced to its prime factors, and the claim having been provided to comprise a combination involving no element which is not essential to a realization of the invention, a new and more important question arises. The elements have been recited in terms fitted to the example of the invention thus far developed. The combination is broadly stated, but the

terms of the elements are limiting. Cannot some ingenious infringer realize the invention by a similar combination escaping the literalism of the terms of the elements? It is at this stage that the claim must be carefully studied. The inventor, or some one for him, must assume the position of a pirate, and set his wits to work to contrive an organization realizing the invention but escaping the terms of the proposed claim. When such an escaping device is schemed out, then the defect in the claim is developed and the claim must be redrawn. In this way every possible escape must be studied so as to secure to the inventor adequate protection for his invention. Solicitors find it difficult to get inventors to do or consider this matter properly, inventors being too often inclined to disparage alternative constructions, the matter being largely one of sentiment founded on the love of offspring. The wise inventor will recognize the fact that the patent which he proposes to get is the deed to valuable property; that the object of the deed is not to permit him to enter upon the property, for he can do that without the deed, but that it is to keep strangers from entering upon the property; that he desires to enjoy his invention without unauthorized competition; that when the property begins to yield profit it will invite competition; that competitors may make machines worse than or as good as or better than his; and that he can get adequate protection only in a claim which would bar poorer as well as better machines embodying his invention. Briefly, then, all good claims for mechanism are combination claims; the fewer the elements recited the stronger will the claim be; non-essential elements weaken or destroy the claim; the claim should not be considered satisfactory so long as a way is seen for the escape of the ingenious pirate.

Combinations and Aggregations.

A given association of mechanical elements may be entirely new, but it does not follow that it forms a patentable association, for not all new things are patentable. If the new association is a combination it is patentable, but if it is a mere aggregation it is unpatentable. An association may be new and still all of its separate elements may be old, the act of invention lying in the fact that the elements have been so associated with relation to each other as to bring about an improved result, or an improved means for an old result. All new machines are,

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after all, composed of old elements. The law presupposes that the elements are old, and that the invention resides in the peculiar association of them. If we take a given mechanical element, recognized as having had a certain capacity, and if we then similarly take some other mechanical element and employ it only for its previously recognized capacity, and if we then add the third element for its recognized capacity, we have in the end only an association of three elements each performing its well-recognized individual office, and the entire association performing only the sum of the recognized individual elements. Such an association is a mere aggregation, a mere adding together of elements, without making the sum of the results any greater in the association than it was in the individual elements. It is simply adding two to one and getting three as a result. An aggregation is unpatentable. As an illustration, a heavy marble statue of Jupiter is found in the parlor and difficult to move. Ordinary castors are put under its pedestal, and it becomes easier to move. Modern anti-friction two-wheeled castors are substituted for the commoner castors, and the statue becomes still easier to move. Castors were never before associated with a statue of Jupiter. Here is a new association, but it is a mere aggregation. The statue of Jupiter has been unmodified by the presence of the castors, and the castors perform precisely the same under the statue of Jupiter that they did under the bedstead. There is no combined result, and there is no patentable combination.

But if an inventor takes a given mechanical element for the purpose of its well-recognized capacity, and then associates with it another mechanical element for its recognized capacity, but so associates the two elements that one has a modifying effect upon the capacity of the other element, then the association will be capable of a result greater than the sum of the results for the individual elements. This excessive result is not due to the individual elements, but to the combination of them. One has been added to one and a sum greater than two has been secured. The modification of result may be due merely to the bringing of the two elements together, so that they may mutually act upon each other, or it may be due to the manner or means by which they are joined. In a patentable combination the separate elements mutually act upon each other to effect a modification of their previous individual results, and secure a

conjoint result greater than the sum of the individual results. The elements of a combination need not act simultaneously; they may act successively, or some may act without motion. As an illustration, assume an old watch in which there was a stem for setting the hands, and assume another old watch with a stem for winding the spring. If an inventor should make a watch, and provide it with the two stems, he would have only an aggregation. But if he employed but one stem, and so located it that it could be used at will for setting the hands or for winding the spring, then he would have produced a combination. The particular instance just given is not a case of the same number of elements producing a result in excess of the individual results of the separate elements, but is rather a case of a lesser number of elements producing a combination result equal to the sum of the previous results of a greater number of elements. A better example would perhaps be a new watch with its two old stems so related that either could be used for setting the hands or for winding the spring.

Genera and Species.

An inventor, being the first to produce a given organization, and desiring to patent it, may see at once a patentable variation on the device. In other words, he makes two machines patentably different, but both embodying his main invention. He drafts his broad patent claim to cover both machines. In his patent he must illustrate his invention, and he accordingly shows in the drawings the preferred machine. The two machines represent two species of his generic invention, and for illustration he selects the preferable species. He drafts his generic claim to cover both species, and he follows this with a specific claim relating to the selected species. The question might be asked, If the broad generic claim covers the selected and all other species, why bother with the specific claim, why not rest on the generic claim? The answer is that it might in the future develop that the genus was old, and that the generic claim was invalid, while the specific claim would still be good. The infringer of the specific claim may thus be held notwithstanding the generic claim becomes void. But the inventor cannot claim his second species in his patent. He can claim the genus, and he can claim one species under that genus, but all other species must be covered in separate patents. It is even unwise to illus-

trate alternative species in a patent, for, in case of litigation, some one of the alternative species might prove to be old. This would have the effect, of course, to destroy the generic claim, but it might possibly have the effect of damaging the specific claim if it should appear that the specific claim was after all merely for a modification as distinguished from a distinct species. Were it not for the danger of broad generic claims being rendered void by discovered anticipations, there would be no need for claiming species, but in view of such possibility it is important to claim one species in the generic patent, and to protect alternative species by other patents.

Combination and Sub-Combination.

A given machine capable of a given ultimate result having been invented, a claim may be drawn to cover the combination of elements comprised in the machine. Such claim will cover the machine as a whole. But, the fact being recognized that many machines are, after all, composed of a series of sub-machines, and that these sub-machines, in turn, are composed of certain combinations of elements, and that within these sub-machines there are still minor combinations of elements capable of producing useful mechanical results, and that the sub-machines, or some of the subordinate combinations of elements within the sub-machines, might be capable of utilization in other situations than that comprehended by the main machine, it becomes important that the inventor be protected regarding the sub-machines and the minor useful combinations. Claims may be drawn for the combination constituting the main machine, other claims may be drawn for the combinations constituting the operative sub-machines, and claims may be drawn covering the minor useful combinations of elements found within the sub-machines. Each claimed combination must be operative. But secondary claims cannot be made for sub-machines or sub-combinations which are for divisional matter or matter which should be made the subject of separate patents.

Mechanical Equivalents.

Where an inventor produces a new mechanical device for the production of a certain result, he can often see in advance that various modifications of it can be made to bring about the same result; and even if he does not see it, he may in the future find

competitors getting at the result by a different construction. He analyzes the competing structure, and determines that "it is the same thing only different," and wonders what the legal doctrine of mechanical equivalents means, and asks if he is not entitled to the benefits of that doctrine, so that his patent may dominate the competing machine.

An inventor may or may not be entitled to invoke the doctrine of mechanical equivalents, and the doctrine may or may not cause his patent to cover a given fancied infringement. If an inventor is a pioneer in a certain field, and is the first to produce an organization of mechanism by means of which a given result is produced, he is entitled to a claim whose breadth of language is commensurate with the improvement he has wrought in the art. He cannot claim functions or performance, but must limit his claim to mechanism, in other words, to the combination of elements which produces the new result. His claim recites those elements by name. If the new result cannot be produced by any other combination of elements, then, of course, no question will arise regarding infringement. But it may be that a competitor contrives a device having some of the elements of the combination as called for by the claim, the remaining elements being omitted and substitutes provided. The competing device will thus not respond to the language of the claim. But the courts will deal liberally with the claim of the meritorious pioneer inventor, and will apply to it the doctrine of mechanical equivalents, and will hold the claim to be infringed by a combination containing all of the elements recited in the claim, or containing some of them, and mechanical equivalents for the rest of them. Were it not for this liberal doctrine the pioneer inventor could gather little fruit from his patent, for the patent could be avoided, perhaps, by the mere substitution of a wedge for the screw or lever called for by the claim. The court, having ascertained from the prior art that the inventor is entitled to invoke the doctrine of equivalents, will proceed to ascertain if the substituted elements are real equivalents. A given omitted element will be considered in connection with its substitute element, and if the substitute element is found to be an element acting in substantially the same manner for the production of substantially the same individual result, and if it be found that the prior art has recognized the equivalency of the two individual elements, then the court will

say that the substituted element is a mechanical equivalent of the omitted element, and that the two combinations are substantially the same. This reasoning must be applied to each of the omitted elements for which substitutes have been furnished. In this way justice can be done to the pioneer inventor. But the courts, in exercising liberality, cannot do violence to the language of the claim. The infringer will not escape by merely substituting equivalents for recited elements, but he will escape if he omits a recited element and supplies no substitute, for the courts will not read out of a claim an element which the patentee has deliberately put into the claim, and a combination of a less number of elements than that recited in the claim is not the combination called for by the claim.

It is seldom that the exemplifying device of the pioneer inventor is a perfect one. Later developments and improvements by the original patentee, or by others, must be depended on to bring about perfection of structure. Those who improve the structure are as much entitled to patents upon their specific improvements in the device as was the original inventor entitled to his patent for the fundamental device. These improvers are secondary inventors, and are not entitled to invoke the doctrine of mechanical equivalents. The secondary inventor did not bring about a new result, but his patent was for new means for producing the old result. His patent is for this improvement in means, and his claim will be closely scrutinized in court, and he will be held to it, subject only to formal variations in structure. The justice of thus restricting the claim of the secondary inventor must be obvious, in view of the fact that if the doctrine of mechanical equivalents were applied to his claim then the fundamental device on which he improved would probably infringe upon it, which would be an absurdity. It is thus seen that the pioneer inventor may have a claim so broad in its terms that its terms cannot be escaped; that he may invoke the doctrine of equivalents and have his claim dominate structures not directly responding to the terms of the claim; that the secondary inventor, who improves only the means, is limited to the recited means and cannot invoke the doctrine of equivalents. But within this general view, sight is not to be lost of the fact that secondary inventors may be pioneers within certain limits. They are not the first to produce the broad ultimate result, but they may be pioneers in radically improving interior or sub-

results, and they may thus reasonably ask for the application of the doctrine of equivalents to their claims within proper limits. The matter often becomes quite complicated, for it is sometimes difficult to determine as to what is the result in a given machine, for many machines consist, after all, of a combination of subordinate machines. Thus the modern grain-harvesting machine embodies a machine for moving to the place of attack, a machine for cutting the grain, a machine for supporting the grain at the instant of cutting, a machine for receiving the cut grain, a machine for conveying the cut grain to a bindery, a machine for measuring the cut grain into gavels, a machine for compressing the gavel, a machine for applying the band, a machine for tying the band, a machine for discharging the bundle, a machine to receive the bundles and carry them to a place of deposit, and a machine to deposit the accumulated bundles. The machine would be useful with one or more of these sub-machines omitted, and each machine may be capable of performing its own individual results alone or in other associations. Pioneership of invention might apply to the main machine, or to the sub-machines, or even to the sub-organization within the sub-machines.

Modifications.

It frequently happens that an inventor, in applying for his patent, can show the preferred structure and lay the foundation for broad claims, while at the same time he can see various modifications capable of the same result. In such case the inventor is often desirous of illustrating such modifications in his patent, and patent solicitors often yield to the desire. It is generally unwise to illustrate and describe modifications. The claim should be of scope to cover the invention and mere modifications of it, regardless of whether those modifications are or are not set forth, and regardless of whether the inventor has conceived of them, so long as they are mere modifications. If he does show modifications, he might in court run up against a rule of law that where there is an enumeration the matter is limited to the enumeration. An infringement might employ a mere modification not comprehended by the enumeration. Again, it is a maxim of law that a mere modification is comprehended by a claim. When the patent is taken into court, it might happen that some enumerated modification might be found to be

old in the prior art, and in such case the claim would fall. If no modification was shown in the patent, then the patentee would be at liberty to deny that the given old device was a modification covered by his claim, thus possibly having his patent maintained for the structure shown in it. If the old modification was set forth, then the patentee could not deny that it was a mere modification of his invention, and that his so-called invention was a mere modification of the old device. Therefore, set forth only the preferred form of the invention, and depend on the scope of the claims.

Divisional Patents.

It may not be possible to cover the several segregable features of a given machine in a single patent. The law contemplates a patent for an invention and not for a number of inventions, and the classification of inventions in the Patent Office, and the organization of the examining bureaus, largely control in determining the matter of divisional applications. A bicycle may be invented which is new and patentable viewed as a whole structure. In such case the claim would recite all of the elements essentially involved in the new organization. But in this bicycle the pneumatic tire may of itself be new and patentable, and the wheel may be of a novel construction, and the lock-nut may be new, and the driving-chain may be new, and there may be a new means for securing the joints of the tubing. These matters cannot be covered in one patent. The improved tire would be viewed as being entirely independent of the peculiarity of the bicycle, and would be susceptible of employment on other kinds of bicycles or vehicles; the wheel construction might be employed in other kinds of bicycles or in wheelbarrows; the chain might be employed in varying situations calling for the use of driving-chains. In the Patent Office the wheel of a bicycle is not treated as a bicycle wheel but as a wheel, for any purpose for which it may be suited. A bicycle chain is not called a bicycle chain, and applications for patents on chains are not examined by the examiner who examines bicycle applications. Lock-nuts constitute a sub-class by themselves. The fact that the arts have recognized these separate sub-classes of devices, and that the Patent Office classification of inventions deals with them as separate and independent elements in the arts, and that the examining divisions of the Patent Office deal

exclusively with given matters—all these facts go to the merit of the question of division of application. The single patent can cover only such matters as are necessarily interrelated to each other. The patent on the bicycle can cover the improved lock-nut in its combination relationship to other features of the bicycle, but it cannot contain a claim covering the lock-nut by itself. The lines of division in the Patent Office are reasonable and necessary lines, and questions of doubt will, on review, generally be resolved in favor of the applicant. If the applicant can afford it he would be wise to resolve these doubts in favor of separate applications.

Solicitors.

Solicitors' fees cover the extended conferences or voluminous correspondence with the inventor; the preparation of the application; the prosecution of it in the Patent Office; the guarding of the inventor's interest in securing all that he is entitled to; and the delivery of the patent. The work is not to be measured by the complexity or simplicity of the invention. An improvement in carpet tacks might involve very much more legal work than an improvement in locomotives. The money value of an invention is often determinable by the merit of the patent granted upon it, and care should be used not to destroy the value of the property at the very start by getting the patent as cheaply as possible. The inventor sees but little of the actual work done by the patent solicitor, the real work being done generally after the application is filed in the Patent Office. It is then that the battle takes place, and it is then that the inventor's property is to be made good or bad. It does not follow that the highest priced service is the best, but it is not likely that the best or even good service will be found at low price.

The selection of a solicitor by an inventor is often to be controlled by the character of the invention. Thus a given invention may call for peculiar mechanical skill on the part of the solicitor. Most all solicitors will be found competent to grasp most mechanical inventions, but a case occasionally arises where extraordinary mechanical skill is required in drawing distinctions between the new invention and its predecessor, the procuration of the patent thus depending very largely upon mechanical skill on the part of the solicitor. In such a case select a solicitor skilled in mechanics, or in the special branch

of mechanics involved in the invention. Another invention may be simple in its device, but the question of obtaining the patent may depend entirely upon fine-spun legal considerations. In such case the solicitor brilliant in the law and dull in mechanics might be the better man. Again, the brilliant mechanic and lawyer might be less preferable than a less talented solicitor in connection with a chemical case. Again, it is always desirable in important cases to have solicitors who have had experience in the particular line in question. Thus, for instance, if one has an important and complicated invention in textile machinery he would be wise to have a New England solicitor, or one who has had New England experience, for that section is the home of the textile arts of this country, and the solicitors of that section have had much more experience than those of other sections. In metallurgy, and in machinery of the soil and harvest, the most competent solicitors would most likely be found in other sections. For general purposes, however, it may be stated, that the competent solicitor can quickly get within his grasp the salient points of most any invention. If he has had proper training and experience the inventor will often be astonished at his capacity for tearing an invention into pieces, sifting out the chaff, and getting right down to the kernel of the invention. Many inventors do not know what their invention is until advised by their solicitors. It is a mistake to suppose that the mechanic is a better solicitor than the lawyer. The lawyer's education is one of analysis, and any mechanic is a better mechanic after studying law. The patent solicitor must have a grasp of the law and of mechanics. He may be a lawyer who has studied mechanics, or he may be a mechanic who has studied law. But it is the law training which fits the solicitor for quick grasp and thorough analysis.

Contingent Fees.

There are all kinds of patent solicitors, as there are all kinds of mechanical engineers and machinists. Perhaps thorough solicitors and engineers and machinists are the exception. The best engineers and machinists can and do generally command the best pay, and so do the best patent solicitors. Those whose competency or reputation will not secure them business at good pay must be content to take poor pay. It may, I think, generally be assumed that the service in any

branch which commands the best pay is the best service, but it does not at all follow that in all cases the best men are getting the best pay. Solicitors who do business on the principle of "No patent, no pay" sometimes do as good work as any one, but the principle is generally availed of by those who cannot otherwise command a satisfactory amount of business. A solicitor of well-established reputation is always in a position to offer his best services, but his best services may not succeed. The more difficult the road to success the greater the need becomes for good service, and the more service is required, hence the inconsistency of contingent fees when coupled with low fees. But the worst aspect of contingent fees is that they are due when the service results in a patent with the ribbon on it. When it is considered that a patent is often the deed for a very valuable piece of property it is obvious that the mere cost of the deed should not be too closely considered. In giving consideration to patent business done on contingent fees, sight should not be lost of the fact that contingent fees are often coupled with the lowest scale of charges. If the charges are low and then made contingent, special caution is suggested.

But there are cases in which a poor inventor must avail himself of the contingent fee system, but it does not follow that the poor inventor should therefore have poor service. He might, perhaps, go to the best solicitor and say to him, "I am poor and want the best legal services, but I cannot meet your charges, and would need to borrow money to meet any charges. I cannot afford the risk of loss, but if I get my patent I will be a rich man. Therefore, join with me in the risk, give me your best service, and if you succeed charge me extra to compensate you for your share of the risk." Some good solicitors can be gotten to render their best services under such an arrangement, the contingent fee being never less than double the ordinary fee. It will be seen that this is not by any means a cheap arrangement; indeed, it is the most expensive possible; but it is often a wise one. It is a safe course only with a solicitor whose reputation is so high that he cannot afford to lower the character of his work in order to expedite the getting of the patent on which alone his fee depends.

Infringements.

A manufacturer, aware of possible infringement upon a given patent, may compare his proposed machine with the terms of the claim of the patent, and may find that his machine escapes the terms of the claim, but he will be quite in the dark as to his status until he becomes advised as to whether or not the state of the prior art was such as to prevent the patentee invoking such a liberal interpretation for his claims as would dominate the proposed structure. Bitter fights occur over questions of infringement, the same as they do over all other asserted titles to property. The inventor creates the new invention and gets his patent, and then may arise a conflict between him and the public; the public seeking to get around the terms of his claim, and he seeking to have its terms expanded to dominate the fancied infringements. If all inventors were pioneers in their lines, then justice could easily be measured out. But in the march of industrial development each inventor adds his mite, and his exclusive rights should be protected, but are often difficult to measure. An inventor may have fancied himself a pioneer and may have gone into the Patent Office with his application, making broad claims. Upon being rejected, in view of the state of the art, he cuts down the scope of his claims, and upon further rejection he cuts down the claims still more, and advances arguments showing delicate distinctions. He then gets his patent, and often seeks to hold it over the heads of the public as having considerable breadth of scope. It is here that the delicate duties of the court are called for in determining the proper limitations to the claim, and hotly contested facts and expert testimony become in order. The courts have referred to cases of this kind by likening certain patent claims to the nose of wax, which is twisted one way to get the claim from the Patent Office, and then twisted the other way to make it reach and dominate an alleged infringement. Experts will always disagree over shadowy lines. The deed to real estate calls for land to the centre of the river, but the river has long since dried up and geological experts may well differ over its former location.

Government Defence of Patents.

Many patentees complain that the Government grants them patents, and then forces on them the burden of maintaining

them; that Government courts often declare the patents weak or void; and they think the Government should sustain its grants.

This view ignores the fact that the Government, in making the grant, can act only on the facts before it. The inventor makes oath that he is the original and sole inventor. It may turn out that the oath is false, and that the invention was gotten complete from the actual inventor and patented with his consent. The Government should not be called on to uphold any such patent. Again, the Government experts search prior patents and the literature of the art, and use their own personal knowledge, and, finding nothing of an anticipating character, the patent is granted. The Government has made fifteen dollars' worth of searches, and the inventor appears to be entitled to his patent, and the patent is accordingly granted. But the Government has no possible means of knowing of unpatented prior public uses. You may invent a peculiar steam engine, and build and sell them for ten years. Some man, a thousand miles from you, invents the same thing, and very properly gets a patent on it, the Government having no knowledge whatever of your past efforts. That patent must fall, and the Government should not be asked to uphold it.

Again, an inventor applies for his patent, and the commissioner rejects him on some old patent which appears to be of anticipating character. Thereupon the inventor files a sophistical argument as to the construction and action of the alleged anticipation, and the examiner, half convinced and resolving doubts in favor of the applicant, allows the application, and the patent is issued. Later, when the patent is taken into court, daylight is let into the sophistry of the argument and it is shown that the old device is the same as the new device. The new patent must fall.

Copies of Patents.

The Government has printed copies of most all its issued patents, and manufacturers and others having to do with patents should more fully avail themselves of this fact. They would do well, if much concerned with patents, to have volumes containing copies of those of interest. The Patent Office divides inventions into something over two hundred classes, and these classes are again divided into sub-classes on more or less

rational lines. There are over six thousand of these sub-classes. The Patent Office will furnish free on application a classification list. Copies of single patents may be purchased for five cents each; if a complete sub-class is taken, for three cents each; if a complete class is taken, two cents each. Any person can procure these copies from the Patent Office at the above figures. The patent attorney would necessarily charge for services in ordering, or for any necessary service. The Patent Office will also enter subscriptions for the mailing of such patents as may issue from time to time in a selected sub-class, a small deposit being made and renewed to cover the cost, at five cents each.

Digests.

Over six hundred thousand United States patents have been issued, and it is unfortunate that the Patent Office has thus far not been able to procure appropriations for digesting them somewhat as the British Patent Office has partially done with its comparatively small number of patents. Such digests of United States patents as have thus far been published are the result of individual enterprise, and the works are necessarily expensive, owing to the great labor and the very limited demand. Manufacturers interested in specific lines of inventions would do well to avail themselves of such digests so far as suitable to their purposes. These digests have been the outgrowth of special activity in certain lines of industry at certain times. I have never seen a complete list of these digests, and do not know that one could be made ; but I here append a list as complete as I can make it, viz.:

Sewing Machine Attachments. By George W. Gregory. 1872.

Breech-loading and Magazine Small Arms, except Revolvers. By V. K. Stockbridge. 1875.

Seeding Machines and Implements. By James T. Allen. 1878. With certain supplements since.

Plows and Attachments. By James T. Allen. 1883.

Agricultural Implements. By James T. Allen. 1884.

Harrows and Diggers, Seeders and Planters, Cultivators, Harvesters. James T. Allen. 1886.

Cycles or Velocipedes, with Attachments. By James T. Allen. 1892. With certain Supplements.

Underground Lines. By James W. See. 1886.

Foreign Patents.

Good foreign patents are extremely valuable property, but it does not follow that all foreign patents are of value. Not one in a hundred of American inventions, even if they are somewhat profitable, are worth the cost and trouble of foreign patents. The cost of foreign patents is heavy, and in most cases the continued validity of the patents is contingent on the payment of taxes and the local working of the invention. If a customer is promptly found under the foreign patent, then its taxes and working offer few difficulties; but if no customer is found within a year it becomes a serious matter to perform the legal working. Little or no confidence should be placed in nominal or paper workings, and even these are expensive. In some countries taxes begin and the invention must be worked at the end of the first year, and the working must not permanently cease; and in the case of Canada the continued validity of the patent restricts the power to import the invention into Canada. An invention which has made good profit in America and is a matter of foreign requirement, is well worth foreign patents, and the customer may often be found in view of the American success. But the trouble is that the foreign patenting cannot be delayed until American success determines its expediency. In some foreign countries the patent would be rendered void by prior patenting or disclosure, and in America the patent expires with the term of the first expiring previously granted foreign patent. Hence, to avoid any antedating, all the patents should bear about even date. Date can be made for foreign patents by merely filing the applications, while in America the date of patent is the date of grant, and may be months or even years after the date of application. Hence the proper course is to take no steps regarding foreign patents till the United States application is allowed. Then select the proper future issue day for the United States patent and cause all the foreign applications to be filed on that day. An exception is to be made in case the invention goes into public use before the issue of the United States patent. In such case the shortening of the life of the United States patent must be submitted to, and the foreign patents should be taken out before public disclosures would render them void.

In most foreign countries patents are granted as a matter of

course, without examination into novelty, and the grant of the patent is no evidence whatever that the patent is good for anything. In Germany applications are examined, and generally rejected. The merit which will insure the grant of a German patent is not at all to be measured by American standards.

Briefly, then, waste no money on foreign patents unless prompt results are in sight, or unless the invention is of importance enough to justify the expense and trouble due to recurring taxes and legal local working of the invention; foreign patents should antedate invalidating disclosures of the invention; it is desirable that all patents on the same invention bear even date. This latter can be secured by filing the foreign patents in the interval between allowance and grant of the United States patent.

DISCUSSION.

Mr. Charles E. Foster.—I think it may be recognized that the subject which Mr. See has brought up is one of general interest to the members of this Society. It is of general interest because it deals with a matter in which there is a lack of information upon certain questions, which causes a great waste of money. During forty years' experience I have seen a very large amount of money wasted in connection with good inventions. There is hardly a man of any intelligence who will invest a few dollars in a piece of property without spending from twenty-five to fifty or a hundred dollars in ascertaining whether he has a title that is worth anything. But the same man who proposes to invest a large amount of money in an invention which he expects will bring him in a much larger sum, will take no trouble whatever to ascertain what steps are necessary in order properly to secure the exclusive right to the invention.

While the necessity of technical claims has come to be pretty well recognized, it is a prevalent idea that any fairly good description is necessarily a good specification. The existence of this idea, and the recognition by inventors and patentees of well-worded and systematically arranged descriptions as specifications, has constituted the basis of a great deal of patent litigation and the loss of protection for many valuable inventions.

The error that underlies this misunderstanding will be apparent when we consider that a mere description applies solely to the thing shown in the drawing, while a specification properly

drawn treats the thing shown in the drawing as a mere incident to the underlying invention.

Except where the invention consists merely of specific details, it always comprises something underlying and broader than any specific illustration thereof, and something which must be expressed in terms which go beyond the description of any single illustration.

Every part of every machine is arranged to perform a certain office or to effect a certain movement; and it is very seldom the case that such office or such movement can be effected only by a single particular construction. So also with results effected by combinations of elements. Each such combination of elements has to perform a certain office or effect a certain movement, and this office and this movement may be effected by other constructions or combinations. It therefore follows that if the specification is so drawn that the elements defined in the claims by reference back to the description are necessarily elements of the precise or approximate character set forth in a mere description, or illustrated in the drawing, then any mechanic, ingenious enough to effect like results by the use of other elements not the mere equivalents of those shown, or by discarding some of the elements described, can avoid the claims.

In construing a patent, the court is practically limited by law to the scope set forth in the specification and claims. If the court, looking into the specification, finds that the inventor has set forth the foundation principles of his invention, the essential things which underlie non-essential constructions; if it finds that he has set forth that certain things are to be arranged or co-act in a certain way to produce a desired effect, but that he has also pointed out that he recognizes that other things may be substituted for those which he has shown, and that parts may be altered or dispensed with; and if, in addition, it finds that he has illustrated different modifications with the view of thoroughly explaining his position upon this point, and that the Patent Office has accepted the position which the inventor has taken; and if the court finds that all the various modifications embody the same principle of construction or operation, then in that case the court, when it comes to consider the claim, even although the latter may be nominally to specific elements, will give a broad construction to that claim, and will consider as infringing devices constructions which are

very different from those shown in the patent. In other words, it will give the inventor the benefit of his declaration that his invention consists not in specific construction and arrangements, but in the combination of parts of any character within proper limits to produce certain effects.

If, on the contrary, the specification consists merely of a clear and exact description of what is shown in the drawings, with a claim, even broad and generic in its terms, the court, owing to the failure to set forth that the said terms apply to anything except to the specific construction shown, will be very apt to limit the claims to such construction, and to find that other constructions, although based upon the same principle of operation, and securing the same result, are not infringements.

In a recent case, one of the Circuit Courts found that a patent, not a foundation patent by any means, was infringed by a simple device which made use of but three parts to effect a certain result, while the construction shown in the patent made use of a complicated arrangement of about a dozen different elements to effect the same purpose, the court, making special reference to the fact that the patentee had stated that he did not limit himself to any precise means for accomplishing the result, and to his having described and illustrated several different means, none of which were used by the defendant.

In Morley *vs.* Lancaster, decided by the Supreme Court, and reported in 129 U. S., the court sustained the claims, which were broadly for the combination of "means" for doing certain things, regardless of the construction of these means; and one of the grounds for giving a liberal interpretation of the patent was, as stated, that "in the Morley patent a modification is described," and that Morley says in his specification "that different means for making a stitch may be employed, as well as other feed mechanisms." The court further, in other portions of its decision, compares the modification described in the Morley patent with the infringing devices to show that they approximated more closely the modification than the devices in the main construction.

I refer especially to this case of Morley *vs.* Lancaster because it is one in which the Supreme Court gave the greatest possible latitude to the claims, and because it appeared that, in doing so, the court was to a great extent governed by the position taken by the inventor in his specification as to what constituted his

invention, and the essential features thereof, and because it is very evident that, if the inventor had merely described his machine without indicating any recognition of the fact that various parts might be supplanted by or substituted for others of very different construction and character, the court, notwithstanding the broad terms of the claims, would not have given so broad a construction to the patent.

No man is capable of writing a specification which will really protect the inventor, whether it be for a stocking supporter or a complex system of electrical transmission, unless he is capable of dissociating his ideas from mechanical constructions and diving down to the foundation principles of the invention. And it is a mistake to think that, because a device is comparatively simple and readily explained, there is therefore nothing else in it, and that there are no underlying principles of operations or construction. Many an inventor of a simple device has missed a fortune because his attorney has not been able to appreciate that the invention back of a simple structure is capable of more than one form of embodiment, and has failed .in his specification to point out what parts are essential and what parts are capable of change or modification, or being dispensed with, in embodying the invention in different forms.

We hear a great deal about the disposition of courts to treat inventors illiberally, but we must recognize the fact that it is generally the imperfect and defective patents which get before the courts. The best test of a patent is that it affords proper protection to the patentee during the term of the patent, without ever affording a basis for litigation; that is, that it is so clear and so explicit that the public recognizes its strength and purpose and limitations, and keeps off the protected ground.

Mr. Albert H. Bates.—The remarks of the last speaker about the specification being drawn broadly are very pertinent. One of the best patent lawyers that we have had, who died recently, said that he preferred to have a very liberal specification, and then the claims just lettered claims; that is, a hanger *A*, a shaft *B*, etc., and then refer back to the specification to find what was meant by the hanger *A*. I doubt, however, if many lawyers agree with him, and it is usually considered that lettered claims are limited in their nature. They certainly require a very carefully drawn specification not to be limited. I think the best practice is to make the claims in words descriptive rather of the

functions of the parts than their structure, and to be very careful that there is nothing in the specification suggesting an unnecessary limitation to the structure; but the Supreme Court has said that although patentees frequently append to their specifications a statement that it shall extend to the whole invention and not alone to the specific thing shown, that that is understood whether set out or not.* Assuming that there is no unnecessary limitation in the patent, its interpretation depends on what the invention consists of. If the invention is a broad invention, the court is going to do its best to give it a broad interpretation, and if there is nothing in the specification or claims to *prevent* that broad interpretation, the court will give it, even though the patentee does not state positively that he wants that broad interpretation. If he points out in his specification that his invention is limited to some particular thing, then the court would have to construe it to cover only that particular thing; but he need not go clear out of his way to set up all the modifications that occur to him, and every time he mentions a thing to say that it is simply preferably this, and something else can be substituted, and all that, because the law considers that the thing that he shows is simply the preferable form, and when he describes that form, the court will consider it an illustration of all that may be covered, and, if the prior art does not show anything to prevent it, they will give the patent an interpretation commensurate with his real invention. At the same time, if the attorney sees that certain things are non-essential, it is undoubtedly desirable to set out that they are non-essential, but I do not think it is to the extent of setting up all the different modifications that come in. A short statement of the invention, and what constitutes the essential parts and broad claims, ought to answer the purpose fully, even though the rest of the specification is purely descriptive of the thing shown, but any unnecessary suggestion that the form shown is the essential form should be avoided.

Mr. See covers the ground so well in his article that I cannot do more than, perhaps, clinch a few of the nails that he has driven, and possibly loosen up one or two that he has driven, as I think, too tightly.

The author says that a caveat does nothing that an application does not do. That is reasonably true if the invention is per-

*Winans *vs.* Denmead, 15 How., 330.

fected, but frequently one does not have the invention perfected; you have the gist of the idea, and so on, but you have not got it worked out in an operative form, and if you apply for a patent on that, the Patent Office very likely will hold that it is so informal that they will not give it an examination; whereas, if you put in a caveat they look very liberally to the explanation, etc., and if anybody else files a later application that would interfere with your invention, the office will notify you, that you may file a proper application and be put in interference with it. I know of a case where an inventor was advised to file an application instead of a caveat, and the Office said that his machine was inoperative and they would not give it consideration until new drawings were filed. The inventor went ahead and got up a commercial machine and delayed filing his new drawings and description until the machine was completed, and meanwhile somebody else filed an application, and he did not know anything about it until a couple of years afterwards; whereas, if he had filed a caveat, the Office would not have hung the matter up for formal objection, and he would have discovered his true status promptly. There is another disadvantage in filing an application for caveat purposes; that is, that there is always the temptation in saving expense, to complete it into a patent, and thereby get a much poorer patent than if you let it go as a caveat. The use of caveats is undoubtedly very limited, but these are cases, it seems to me, where it is a good thing to file them.

Mr. See's remarks on hurried applications I think will bear a little qualification. I refer to his suggestion that if an invention is a short-lived invention to get it patented immediately, otherwise to delay nearly the period of two years before patenting it. There is always danger in the process of delay, for the reason that somebody else may come in and get a patent, and although you can have an interference with a patent, your chances are not as good as with a pending application, for this reason: if there are two applications pending in the Office at the same time, the Office will simply give the preference to the one that is earlier, throwing the burden of proof on the other; whereas, if the patent is issued, the *public* has notice that that patentee is the owner of that invention, and they have a right that that patent shall not be lightly overthrown. Hence it follows that it takes a good deal more proof to overthrow a

patent than an earlier application. Therefore it seems to me that as soon as the invention is substantially completed, so that you know what you want, the thing to do is to apply for a patent right away and not wait for the two years. There are some inventions which are as valuable seventeen years from now as they are now, but most inventions are not, and the difference between a sixteen and a seventeen year patent makes very little difference in the majority of cases.

What Mr. See says about stealing inventions I think is very good. Likewise the matter under several of the following headings:

There is a great deal of misunderstanding about the rights of joint inventors. In fact the law is not absolutely settled on the point. But the public usually thinks that if one man owns one-tenth of an invention and another man owns nine-tenths, that they share all right in proportion of one to nine. That is not so. The man who has one-tenth has the same right to use the patent as the man who owns nine-tenths. He has the same right to license others. The nine-tenths man cannot enjoin his licensees, and they have as much right as the licensees of the man with nine-tenths. The probability is that the nine-tenths man cannot compel the one-tenth man to pay over anything that he has received from licensing, but that point is not absolutely decided. The trend of the decision, however, is that each man may use the patent as he sees fit and to the best of his ability, and put in his time and money, and be entitled to whatever he can get out of it, and if one man goes ahead and licenses every Tom, Dick, and Harry in the neighborhood, the only recourse of the other man is to go to some other neighborhood and license every Thomas, Richard, and Henry there.

Mr. See's remark not to be satisfied with a claim if there is seen any way to get round it, of course only applies to fundamental inventions, because most inventions are not entitled to any such broad claims that there is not a way to get around them.

As to showing modifications, there is this to be borne in mind, that where a man has a broad invention, he may see a whole lot of modifications which in themselves are inventions, and he may not think it worth while to patent them separately, but he may not want anybody else to do it. Hence, if he shows his particular invention and then all these different modifications,

even though it is only his broad claim that covers them, still if that broad claim should be knocked out and he is not able to hold those modifications, they are shown there and every one else is prevented from covering them. It is perhaps a little embarrassing when it comes to a suit on an invention to find that a part of the thing shown in the patent is old, while another part that has been treated as a modification is not old, and have to distinguish between them, but at the same time it can be done all right. All the patentee has to do is to disclaim one part, and he is not stopped from claiming that what is left is a different thing from what is shown. But if the modifications are simply mere modifications which are not of distinct scope, so that it would be no invention to make them in view of the main thing shown, it is certainly superfluous to show them, and they had better be omitted, for, as Mr. See says, they can be no good and may embarrass the patent. But where the modifications are themselves subinventions of the main invention claimed, I think it is a good thing to show them, so as to prevent somebody else from patenting them later.

As to the Government defence of patents, it is frequently urged by people that the Government, if it grants a patent, ought to protect it. But it is simply a question of money. You pay the Government $35 for a patent, and the Government gives you all it can afford to give for $35. If the Government was to guarantee patents and take the responsibility of their always being valid, it would have to charge an enormous sum. The result would be that every man who wanted a patent would have to pay perhaps a thousand dollars for his patent no matter what it was on, and when its validity was unquestioned. But now you only pay the expense consequent on getting the patent, and with those patents which do not have their validity tested there is no other expense, and those that do have their validity tested bear the expense that is consequent upon it. So I think that Government defence of a patent is out of the question. It is better to go to the courts and let those who are benefited stand the expense.

On the question of foreign patents, there is an oversight in Mr. See's paper in the statement that "in America the patent expires with the term of the first expiring previously granted foreign patent." That was true up to the first of last January. But we now have a law that renders the United States patent

independent of the foreign patents, and hence there is not the trouble that there used to be. Formerly if the patent in England was published to-day, and the United States patent came out to-morrow, the United States patent would run fourteen years instead of seventeen. That is no longer the case. The requirement now is that the application in this country must be filed not later than seven months after any foreign application, but outside of that there is no term limitation.

Mr. See's remarks as to foreign patents being usually a waste of money, etc., I think are very true, with some exceptions. In England there is no requirement for working the invention. The taxes do not begin until the end of the fourth year, and they are not very large then. You are dealing in the English language and the customs and methods of trade are comparatively familiar, and an English patent is very frequently valuable and very frequently easy to handle. But in the other European countries where the language is different and you have difficulty in getting into communication with the people, where there is a requirement that the invention must be worked in the country within two or three years, and where the taxes come due every year, the great probability is that it will cost a good deal more than you will get out of it. The probability is that you will not be able to dispose of the patent, and you will have some nominal sort of working to keep it up for three or four years, and then get tired and stop. That is the usual result, I think, of European patents, with the exception of England. But in England, on account of the language being the same, and because there is no working requirement, and you have more time before the taxes begin, I think patents very frequently result beneficially.

In Canada, the patent will prevent your sending goods from the United States into Canada after a year (or at most after two years, if the time is extended), and very frequently that is more disadvantageous to a man than the patent in Canada is an advantage. If his factory is here, he usually wants to make here and sell in Canada; but if he does so it invalidates his Canadian patent. If he wants to manufacture over there, however, he can get the time for making extended periodically for quite a time. The law says he shall work it within two years unless, for cause shown to the satisfaction of the commissioner, that time is extended. I have in mind one patent where we got the

time extended up to five years. It is on its fifth year now. The cause we showed to the commissioner was that the inventor was financially unable to work it in Canada, and the commissioner granted the extension. There are no taxes there until the end of six years. So that what Mr. See says does not apply to Canada with the same force that it does to the other countries. But, with the exception of England and Canada, I think that what he says is correct.

We very frequently hear it said, as if it were a slur on the patent system, that one can get any little thing patented. Now it ought to be borne in mind that the *patent* one gets is no larger than the *invention*. If it is an invention of a limited character the patent is correspondingly limited, and, in manufacturing the device, it may be easier to avoid the patent than it is to infringe it. A man gets up a little bit of an invention—a bicycle wrench, for instance. He gets a patent on that which is limited to the specific form of wrench which he uses. The Patent Office thinks there may be invention in it, and they will solve the doubt in his favor. But there is no harm done to the public, because if that wrench is not an advantage they will not use it; they will use some other style of wrench. Hence it does not seem to me it is any detriment to have things of small invention patented. If a thing is so essential that it is the only thing that will do the work, a man ought to have a broad patent and cover everything. On the other hand, if it is a little bit of an invention there is no harm in letting him have a little bit of a patent.

Mr. W. W. Varney.—I have examined with care the paper by Mr. See on patents. With one or two minor criticisms I must say that the paper is one of the most concise and accurate statement of the headings treated which I have ever seen, and would urge upon members of the Society at all interested in the subject of patents to read every word carefully.

Under the heading "Stealing Inventions," I would like to put out a suggestion which is followed by many inventors, and that is, when you think of an idea make a sketch of it at once, no matter how crude or how insignificant you may think the invention is at the time, show it to some one who understands it, explain it to him thoroughly, have him sign his name as a witness and the date that you showed it to him; this kind of evidence will help you amazingly in interference proceedings.

Under the heading "Combination Claims," the matter there ought to be carefully studied; almost nine out of ten patents are practically worthless on account of containing too many elements.

Under the heading of "Employers' Rights," the text seems to be accurately drawn, but in one or two points it appears to me, in the example given, possibly misleading.

I give here a brief extract from a Supreme Court decision bearing upon this point:

Solomon *vs.* United States' 137 U. S., 345 (U. S. Supreme Court). "The case presented by the foregoing facts is one not free from difficulties. The Government has used the invention of Mr. Clark, and has profited by such use. It was an invention of value. The claimant and appellant is the owner of such patent, and has never consented to its use by the Government. From these facts, standing alone, an obligation on the part of the Government to pay naturally arises. The Government has no more power to appropriate a man's property invested in a patent than it has to take his property invested in real estate; nor does the mere fact that an inventor is at the time of his invention in the employ of the Government transfer to it any title to or interest in it. An employee, performing all the duties assigned to him in his department of service, may exercise his inventive faculties in any direction he chooses, with the assurance that whatever invention he may thus conceive and perfect is his individual property. There is no difference between the Government and any other employer in this respect. But this general rule is subject to these limitations. If one is employed to devise or perfect an instrument, or a means for accomplishing a prescribed result, he cannot, after successfully accomplishing the work for which he was employed, plead title thereto against his employer. That which he has been employed and paid to accomplish becomes, when accomplished, the property of his employer. Whatever rights as an individual he may have had in and to his inventive powers, and that which they are able to accomplish, he has sold in advance to his employer. So, also, when one is in the employ of another in a certain line of work, and devises an improved method or instrument for doing that work, and uses the property of his employer and the services of other employees to develop and put in practicable form his invention, and explicitly assents to the use his by

employer of such invention, a jury, or a court trying the facts, is warranted in finding that he has so far recognized the obligations of service flowing from his employment and the benefits resulting from his use of the property, and the assistance of the coemployees of his employer, as to have given to such employer an irrevocable license to use such invention."

It appears to me from the above that in the last case given in Mr. See's illustration, that not only would the shop-owner have an irrevocable shop right, but would be absolute owner of the invention and could compel the inventor to assign him the patent if he should patent it.

Under the heading "New Purpose," page 625, the text is accurately and very clearly drawn, but thinking that possibly it might mislead some, I want to call attention to process patents in which the same machine might be used to do one thing for which it was applicable, but could not be used to do another thing for which it might also be applicable.

To illustrate: A bread-kneading machine may be patented and capable of thoroughly mixing bread, *i. e.*, of thoroughly mixing water, salt, yeast, and flour; it might also be capable for use as a mortar-mixing machine, but some one else might have a process patent on the mixing of mortar, *i. e.*, the process of mixing lime, sand, and water together. Now obviously the owner of the bread-mixing machine could not use the machine for mixing mortar, even if his machine was capable of such use, otherwise he would infringe the mortar process patent; therefore the last clause of Mr. See's paragraph, viz., "An inventor is entitled to all the capabilities of his invention," might possibly have added, "but cannot use his invention to infringe other persons' processes."

Under the head of "Foreign Patents," page 641, I find this: "And in America the patent expires with the term of the first expiring previously granted foreign patents," and allowing thereafter the method of procedure concerning the obtaining of foreign patents in conjunction with United States patents.

A year ago that was good law and advice, and doubtless Mr. See, in preparing his paper, overlooked the fact that the Fifty-fourth Congress amended Section 4887 of the Revised Statutes, which read as follows:

"No person shall be debarred from receiving a patent for his invention or discovery, nor shall any patent be declared invalid

by reason of it having been first patented or caused to be patented in a foreign country, unless the same has been introduced into public use in the United States for more than two years prior to the application. But every patent granted for an invention which has been previously patented in a foreign country shall be so limited as to expire at the same time with the foreign patent, or, if there be more than one, at the same time with the one having the shortest term, and in no case shall it be in force more than seventeen years,"

To read as follows, which is now the law:

"No person otherwise entitled thereto shall be debarred from receiving a patent for his invention or discovery, nor shall any patent be declared invalid by reason of its having been first patented or caused to be patented by the inventor or his legal representatives or assigns in a foreign country, unless the application for said foreign patent was filed more than seven months prior to the filing of the application in this country, in which case no patent shall be granted in this country.

"To take effect on the first day of January, 1898."

Hence the only limitations we now have concerning foreign patents in their effect upon United States patents is:

"Unless the application for said foreign patent was filed more than seven months prior to the filing of the application in this country," and a clause concerning this point is now required by the Patent Office in the oath made by applicants.

I submitted Mr. See's paper and my remarks to my old classmate and brother solicitor of Baltimore, Mr. George C. Morrison, and requested him to reduce his comments to writing, and you will notice that he takes the opposite view concerning employees' rights from what I do:

May 26, 1898.

WILLIAM W. VARNEY, ESQ.,
118 E. LEXINGTON ST., CITY.

My dear Mr. Varney: I have read Mr. See's very excellent epitome of patent law and practice with a great deal of pleasure, and I hope profit.

I agree most heartily with what you say about the advisability of establishing a definite date of discovery. I myself know of several cases that have come very near to being lost for want of some such procedure as you suggest.

As to the question of an estoppel as against an employee. It has always seemed to me that this question of employers' rights rested entirely upon the question of contract. Of course in almost every case the contract would have to be verbal or implied to admit of controversy, still the recovery or decision has always seemed to me to have been based upon the contract which the court was able

to extract from the evidence. For instance, using Mr. See's illustration, if the ingenious carpenter so employed performed his labor under a general contract to do the best he could, and while so employed made certain improvements which he incorporated into his employer's work, I do not think that the employer's license would extend beyond the actual articles constructed by the said employee. I do not think that the employer would even have the right to employ others to utilize his first employee's ideas, even during his term of employment, without his consent, express or implied. An implied consent might of course be presumed from a failure to object. I do not think that the employer can secure any right not voluntarily given him by his employee. On the other hand, the license once given cannot be recalled. This is the point upon which most of the cases have turned. The employee, to curry favor with his employer, has introduced his invention into his employer's business, and has allowed the employer to make free use of it. Then, upon leaving his former employer, he has tried to withdraw his former implied consent to use, and has been denied that privilege by the courts. From this has arisen the doctrine of what might be called "Employers' rights by accretion," a doctrine which I believe to be wrong.

Of course it is undoubted that if I employ a man on the ground that he has inventive genius, and agree to give him so much salary, provided I am to receive the product of his brain, I am entitled to receive that product, whether it be invention or something else. The whole thing seems to be governed by the principles of contract, and nothing else. If you have time you might look at the cases of McClurg *vs.* Kingsland, 1 How., 202, and Whiting *vs.* Graves, 3 Bann. & A., 222. Thanking you for the privilege of reading Mr. See's paper, I am,

Very truly yours,

George C. Morrison.

Mr. Ezra Fawcett.—The paper presented is a very elaborate digest of patent law, and seems to give a clear version of the aims and objects of equitable patents. Some recent issues and decisions, especially some electrical patents, such as the "fundamental transformer" (which has been in text-books over forty years to my knowledge), and others, questionable, which are common "shop kinks," seem to belong to a class different from those discussed by the author of the paper. The many patent solicitors who get up specifications on the "no patent no pay" plan frequently make them so vague that, as the saying, is it would take a "Philadelphia lawyer" to get at the special point claimed. For instance, I myself have a patent on a shaft governor about which, from the reading of the specifications, one not familiar with that particular governor could not tell anything, except in a vague way.

Mr. C. W. Baker.—The only criticism that I can make upon Mr. See's paper is that perhaps he has made it a little too technical for most mechanical engineers, who know very little of patent law. I believe it is an excellent thing for every mechanical engineer to know all he can on the subject of patents, pro-

vided he does not attempt, on the strength of slight knowledge, to act as his own patent solicitor.

I wish that Mr. See had laid more stress on some of the very simpler matters about which comparatively few engineers are as well informed as they should be, and especially the matter of preliminary examinations. It is not generally known how easy it now is to make a fairly thorough search of the prior state of the art in any invention, through the classification which the Patent Office has adopted, and which should be in every mechanical engineer's library. Anyone can get the pamphlet containing this classification by sending ten cents to the Commissioner of Patents. The question which is continually coming up in every manufacturing establishment and in the practice of most engineers is: Is this or that scheme new? Can it be patented? Has it been patented in any form? Now, by taking this official classification and finding in it the sub-class under which the invention probably belongs (and I think in nine cases out of ten you can determine this with reasonable certainty), and then sending to the Patent Office at Washington the sum of three cents for each of the patents in that sub-class, you will be able to obtain the complete state of the art so far as United States patents are concerned. With the average new idea which occurs to the average man I think in most cases he will find that his idea has been anticipated when he looks over these prior patents, and will be saved the expense of applying for a patent on a device which is not novel. On the other hand, if he finds on looking over these patents that his idea is novel, he will very likely get some valuable hints as to what others have done in the same field, which will greatly assist him in perfecting his own idea. Further, if he decides that it is worth while to proceed with his application for a patent, the knowledge of what previous patentees have already covered will be of very great assistance in drafting the specification and claims so that he may most perfectly protect his invention.

Mr. Bates.—This matter of preliminary examination is one of considerable importance in respect to saving expense to the inventor. The members of this Society would undoubtedly, by getting sub-classes, understand them, but most inventors could not; most inventors would get those sub-classes and would not know any more than they did before. They would pay perhaps $3 for a hundred patents and could not tell what they showed

and what they did not. I think it is considerably more than one invention in ten that is not in any specific sub-class. They are liable to run over three or four sub-classes, or more, and it has been my experience that ordinarily it is a good deal more satisfactory to have a representative in Washington to go over to the Patent Office and search through the sub-class where he thinks the thing would probably be, and if he does not find anything like it, to search through other allied sub-classes, than it is either to try to buy all the sub-classes or to buy those of the particular sub-class that the invention relates to.

In regard to this question of new purpose, which Mr. See speaks of, and which was brought out by another paper, although it is the general rule that you cannot get a new invention by turning an old machine to a new use, that must be taken with an explanation. If it is transferred to an entirely different art, the courts have held that a very slight change, which in the same art would not amount to anything at all, may confer patentable novelty on it. In a recent case on a patent on a clay disintegrator there was cited an old machine for polishing wood which embodied the reconstruction of the patent, except in having certain parts of glass instead of steel, and the court below held that that was an anticipation, but the Supreme Court said that it was not; that the arts were so dissimilar that, even though the change was very slight, there would still be invention in taking that old wood-polishing machine and changing it so that it would do for disintegrating clay.* Thus it sometimes comes down to the point that the art is so very dissimilar that what is really the same structure or process may be patented again, when limited to the new use. There is a case I call to mind, when, against the patent on the sand blast for etching on glass, there was set up a patent showing a sand blast on a locomotive for scaring cattle. It was in the old days when trains ran slowly, and if a cow got on the track they blew sand against her; and the judge said something like this: "It is gravely contended by the attorney for the defence that the only difference between this invention and the prior patent is that in this case the sand hit glass, and in the other case it hit a cow. Verily that is the only difference, but that difference amounts to invention"—and he held the patent valid.† So it

* Potts *vs.* Creager, 155 U. S., 597.

† Tighlman *vs.* Morse, 9 Blatch., 421.

may sometimes be that the arts are so very dissimilar that it involves invention to see that you can use one old thing for a new purpose.

One word more about dating drawings, etc. It would be of a great advantage to all inventors if every time they made an invention, they made a sketch of it, and wrote their name on it, and put the date on it, and had it witnessed. When it comes to a contest, memory does not count for very much. You can remember that you had a certain thing at a certain time, and it may go to prove that you had it, but it won't prove the exact date when you did have it; whereas, if there is a drawing signed, dated, and witnessed, and you and the witnesses swear it was signed on that day, you have a fairly good case, and it would be hard for the other side to discredit the evidence. I remember a remark of Mr. Charles F. Brush that he had had a hundred interferences in the Patent Office (perhaps the word "hundred" was used to mean simply a large number), and that he won them all but one, and that he considered that the reason he had been so successful was that he never made an invention without making a sketch of it, and having it witnessed and signed and dated and filed away. So he always had the proof for every invention he had made, which resulted very beneficially in his cases.

Mr. Foster.—There is just one word about the last point raised by Mr. Bates, and that is what date will the courts and the Patent Office give to an inventor as the date of his invention? It is an unfortunate thing that the courts of the United States change their minds, not only on income taxes but on matters connected with patents. For a long time the courts of the United States followed the decision in Loom Company *vs.* Higgins, which was to the effect that an inventor could date back his invention to the date when he made his first sketch and description, and to a certain extent that is still adhered to; but the courts, and the Patent Office especially, have gradually shifted their ground until now they generally take the position that the man to first make the actual machine is the first inventor. It is an unfortunate thing; I do not agree with it, but it is a fact, and a fact that we should all recognize in our efforts to protect inventions. Time and again the courts, and the Patent Office lately, have decided as between two parties, where one made a drawing and even a model, that these acts are not sufficient to defeat the

later party, the first to make an actual machine. I have in mind a case where one of the members of this Association made a drawing and a model of a switch-stand, and six months afterwards another man made a full-sized switch stand; the Patent Office gave the patent to the later inventor who made the full-sized switch stand; and that position is becoming confirmed more and more. There is, however, a way of avoiding this difficulty. The courts and the Patent Office recognize that the date of the application for a patent is constructive reduction to practice; so that the man who has filed his application is considered to have reduced the invention to practice first against the other who was the first to make an actual machine, but later than the application of the other party. This shows the disadvantage of applying for a caveat. It costs $10 for a fee for a caveat and but $15 for an application. If a man files an application he gets that date as a date of construction and reduction to practice as much as if he made a machine at that date. No such advantage results from a caveat. The apparatus may be imperfect. If that is so, the inventor can let the application lie. It may run for a year or two. In the meantime he may perfect his machine and then file another application and take patent out on that application. As the law is now interpreted, it is certainly of very great advantage to get the application into the Patent Office at the earliest possible date.

Mr. Albree.—There is one point I would like to have made a little clearer. That is in regard to the right of an employer in an employee's invention, whether it involves simply a shop right to use the invention, or whether it is broader than that and gives an absolute license so that he could manufacture the article and sell it.

Mr. Foster.—That depends a little on the character of the invention. If the invention consists in a machine, for instance, for making a new kind of buckle, and the employee and inventor has permitted the employer to make a machine that will make the buckles, of course the employer is entitled to use that machine and sell the buckles. If, for instance, it is a puddling furnace, the employer can use the process of that puddling furnace, but he cannot transfer the right to use the machine or process or sell the product to any other party. If the process of puddling involves a new metal—assuming that we should have such a case—the employer that has the right to use the

puddling furnace would have the right to sell the metal. It depends a great deal on the character of the invention. But the thing that the employer made with the consent of the employee he has a right to use, and if it results in a product which can be sold he has a right to sell that product of the particular machine made with the inventor's consent.

The general law is stated in Robinson on Patents, as follows:

> "An employer, simply as such, has no right to the inventions of his employee. If he contracts for his employee's *inventive* skill, and pays him for its exercises in his behalf, he may thereby become the equitable owner of the inventions which result, and be entitled to an assignment of the patents when they are obtained. If their agreement is that the employer shall have the benefit, or the exclusive benefit, of the invention of the employee, this is an express license to the employer to practise the inventions, but leaves their ownership to the inventor. But where, without any express agreement to that effect, an employee uses the time and tools of the employer in making an invention, and then applies it practically in the employer's business, the law implies a license to the employer to continue his enjoyment of the invention, even after the relations between himself and the inventor have been dissolved. The duration of his license in such cases depends upon the nature of the invention. If it is an art he may practice it until the original term of the patent has expired. If it is an article he may use it until it is worn out, and repair it as long as its identity can be retained. His license, however, is not transferable like that of a purchaser of a patented article."

Prof. S. W. Robinson.—There is one point that is often overlooked in these cases and it is this: A man makes an invention and applies to an attorney to prepare his papers and present them to the Patent Office. Suppose that attorney delays this work six months. In the meantime a neighbor comes on three months after the first man has made his application to the attorney to prepare his case, and makes his application and gets his patent ahead of the man who really made the invention—the first man who made a sketch of it, etc., and has made his application through a patent attorney. I wonder if there is any redress for that individual.

Mr. Bates.—I knew of a case of that very kind, where the attorney held the application up for six months before filing. The inventor wrote to him several times and asked him why he did not go ahead with the thing. The attorney was busy about something else, and he did not go ahead with it for six months, and it got into interference, and the Patent Office held that there was negligence on the inventor's part in not poking the attorney up oftener, or in not taking it to another attorney; or,

in other words, that the inventor was not excused from the attorney's negligence. Although he had been the first to conceive, he was held negligent in reducing it to practice. He had invented it, I think, a couple of months before he turned it over to the attorney, and then the attorney held it up for six months. It was a thing that did not require any particular time to reduce to practice. In the meanwhile some one else had gotten it up a little later than he did, and filed his application. The Patent Office held that the first inventor had not used reasonable diligence. As I understand it, the law is that the first to reduce to practice is entitled to the patent, provided that there is not an earlier man to conceive, who was using reasonable diligence to get his invention reduced to practice. Or, to state it another way, the man first to conceive is entitled to the patent, unless some one later to conceive gets it reduced to practice first, and the first man did not use reasonable diligence in reducing his invention. But that question of reasonable diligence is undoubtedly being held more and more rigidly all the time, and the sound policy is to get the thing reduced to practice just as quickly as you can, and if the attorney does not file the application as soon as he ought to, why, the best expedient I know of to make him hurry up is to pay him in advance!

*Mr. James W. See.**—Regarding foreign patents, Messrs. Bates and Varney are quite right regarding the new law. Under the new law, United States patents will not be granted for inventions sought to be patented abroad more than seven months before seeking the United States patent, but, otherwise, the foreign patenting has no effect on the United States patent. Now, foreign applications must not antedate United States applications more than seven months, and United States patents should not antedate foreign patents at all.

NOTE.—It may be of interest in connection with the above paper to call attention that a bill is pending to give the Patent Office an increase in staff and appropriation. It provides for three chief examiners, and about fifty additional assistants and clerks. This is the first increase in the force in many years. I am informed that much of the credit for this undertaking is due to Mr. Duell.—SECRETARY.

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* Author's closure, under the Rules.

DCCLXXVIII.*

BENDING TESTS OF LOCOMOTIVE STAY-BOLTS.

BY FRANCIS J. COLE, PATERSON, N. J.
(Member of the Society.)

No parts of a locomotive require so careful and systematic inspection, to maintain them in a safe-working condition, as the stay-bolts.

Speaking generally, their life, that is, the interval which elapses from the time the boiler was new or the stay renewed, to their fracture, varies from about one to five years or longer. Probably the average would not exceed five years in all classes of engines. This depends, however, upon the length and height of fire-box, steam pressure, size of boiler, width of grate, etc.

The stay-bolts in a boiler of large diameter, with the fire-box between the frames and small curves or radii, connecting the circular portion with the vertical sheets of the fire-box shell, may always be expected to have a shorter life than in a boiler of the same length of grate but of smaller diameter, with the fire-box on top of the frames.

As modern requirements demand large boilers, high steam pressures, long fire-boxes, etc., in short, the very conditions which ought not to exist if the stay-bolt alone were considered, their life may reasonably be expected to be shorter than in the past, owing to the construction necessary for heavier, more powerful and economical engines.

The stress on a stay-bolt produced directly by the steam pressure, tending to force the two sheets apart, is a comparatively small factor in causing its fracture, the tensile stress alone being only $\frac{1}{8}$ to $\frac{1}{10}$ of the ultimate strength, which, if not complicated by the expansion and contraction of the fire-box, causing bending in addition, would in itself never produce a fracture. It follows, then, that the property of a metal to resist repeated bendings is

* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

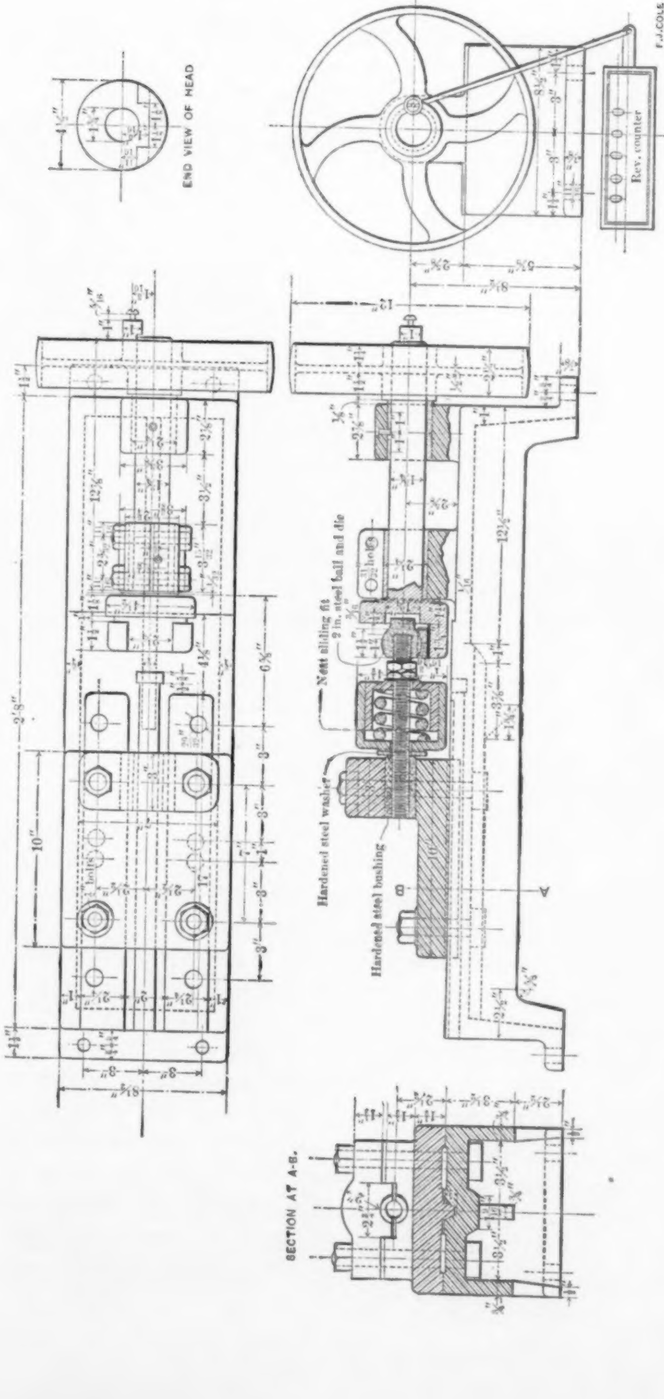
END VIEW OF HEAD
Rev. counter
F.J.COLE
Neat sliding fit
2 in. steel ball and die
Hardened steel washer
Hardened steel bushing
SECTION AT A-B.

FIG. 156.

more valuable than its strength to resist extension or fracture in the direction of its length.

Following out this general idea that stay-bolt iron should be tested for bending under uniform conditions of motion and rigidity with the usual tests for ultimate strength, elongation and elastic limit, a number of different makes of iron were tested on a machine especially designed for the purpose. These tests were made by the writer about three years ago.

In designing the machine two features were kept prominently in view; viz., to make the machine rigid and to clamp the specimen so tightly that no motion would take place in the fixed end, and at the same time to strain it by tension in imitation of the stress produced by the steam pressure.

Its construction is so clearly shown in the drawing Fig. 156 and photographs Figs. 157 and 158, that an extended description will be unnecessary.

Although the machine is arranged to test pieces 3, 6, and 9 inches in length, the tests were all made with a uniform length of 6 inches, measured from the centre of the bolt to the face of the hardened steel die, on account of the difficulty experienced in obtaining any reliable spring pressure with the bolt shorter than 6 inches. The liner used in the machine for all specimens was $\frac{1}{16}$ inch thick, making the free end of the stay-bolt describe a circle $\frac{1}{8}$ inch in diameter. Great care was taken to clamp the bolt so securely in the machine that the movement of the projecting end was scarcely appreciable.

The spring pressure used in all cases was 2,400 pounds, corresponding to the strain exerted by the steam pressure in a boiler where the stay-bolts are spaced 4 inches centre to centre, with a steam pressure of 150 pounds per square inch.

It is clearly shown, I think, by these tests that the principle of the machine is correct, and that the solid, durable manner in which it is designed eliminates most of the variables which have hitherto made these bending tests of but little value. The average general results which the different qualities of iron gave followed closely the quality and value of iron for actual service. The imitation by the machine of the strains produced in a stay-bolt, when screwed in a boiler, is very close; and while some of the tests of the same bar show a larger percentage of difference than in the tensile tests of the iron, yet this is probably accounted for by the fact that in case the threads were cut sharper, or any

flaw existed in the iron, its effect would be very much more marked and exaggerated than would be shown by an ordinary tensile test. While the individual tests of specimens cut from the same bar are somewhat erratic in a few instances, yet the

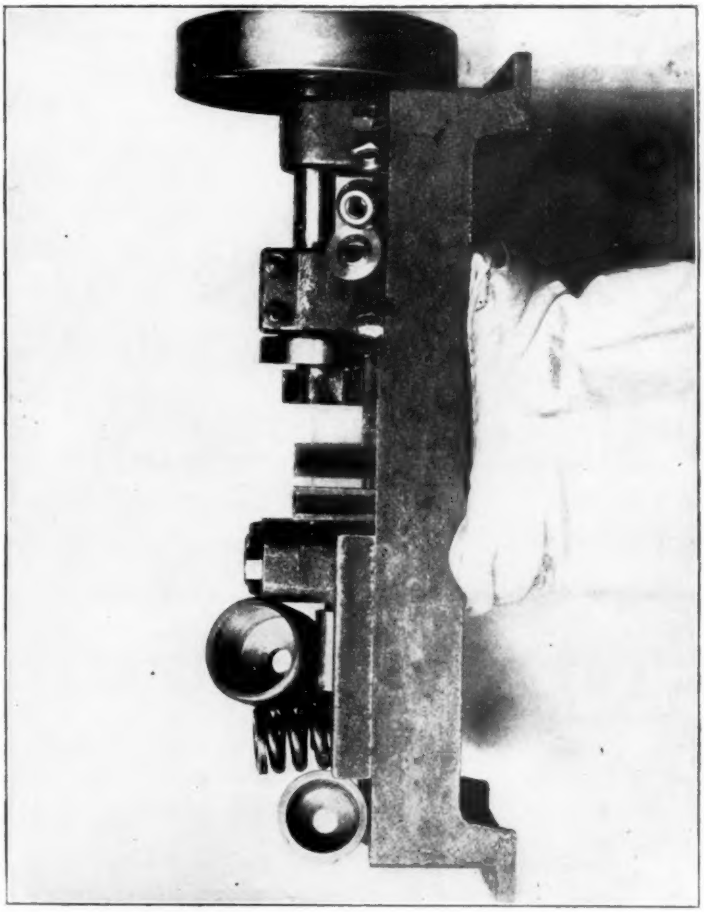

FIG. 157

average of the tests cut from the same bar seems to follow smoe well-defined law.

Cutting off the threads and reducing the size of the middle of the specimen (Fig. 159) do not in these tests indicate a sufficient

degree of improvement in prolonging the life of the stay-bolt to warrant the extra expense. It appears that after a bolt is reduced and turned down a sufficient amount to equalize the strain, and to distribute it over a considerable portion of its

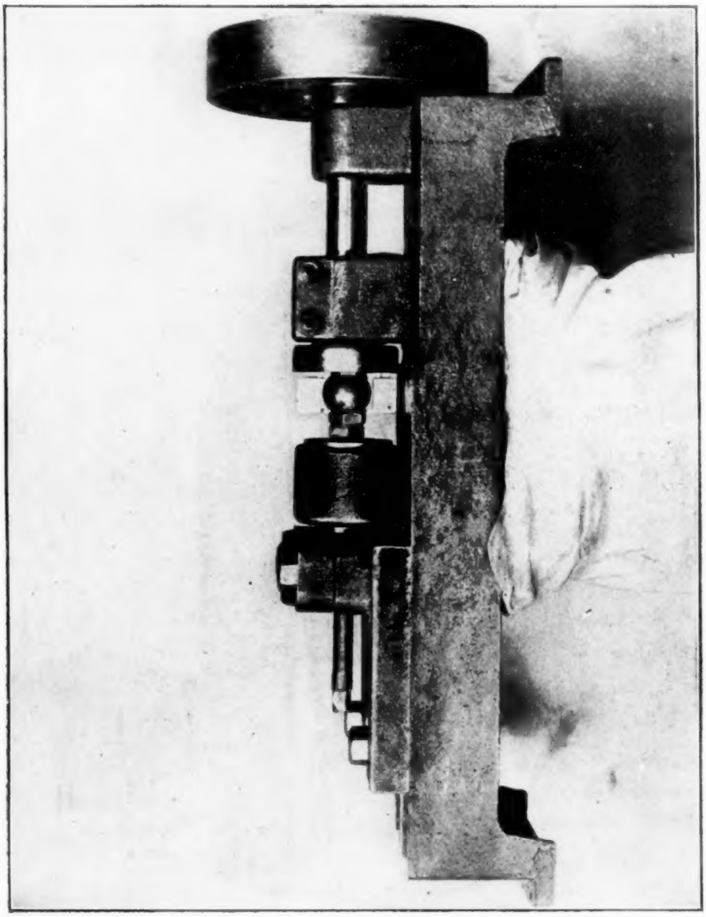

Fig. 158.

free length, the stress produced by the pressure of the spring runs up to such an extent, per square inch of section, that the combination of bending and extension stresses exercises a marked influence in shortening the life of the bolt.

The table given below indicates, for a uniform pressure of 2,400

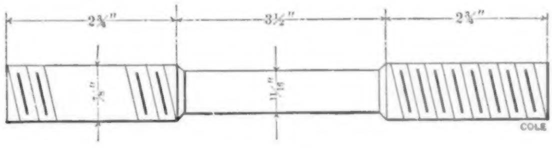

FIG. 159.

pounds, the stress per square inch of section on the different diameters of reduced bolts:

Size.	Area.	Stress.
1 inch.	.7854	3,050 pounds.
$\frac{15}{16}$ "	.6903	3,475 "
$\frac{7}{8}$ "	.6013	3,990 "
$\frac{13}{16}$ "	.5185	4,630 "
$\frac{3}{4}$ "	.4418	5,430 "
$\frac{11}{16}$ "	.3712	6,465 "
$\frac{5}{8}$ "	.3068	7,820 "
$\frac{9}{16}$ "	.2485	9,658 "
$\frac{1}{2}$ "	.1963	12,226 "

After experimenting with the $\frac{7}{8}$ inch bolt reduced to the different diameters, it seemed plausible that by increasing the diameter to 1 inch, and then reducing the section, a marked improvement might be made. This, however, did not seem to prolong the life to any great extent.

The approximate cost of renewing stay-bolts, a few at a time, is as follows:

Cutting out one broken $\frac{7}{8}$ inch stay-bolt, retapping holes, and putting in new bolt	18 cents.
Riveting up two ends	2 "
Total cost of renewing stay-bolt	20 cents.

This does not include taking down or putting up any parts of machinery which may be in the way of renewing the stay-bolt. In round figures, the minimum cost for labor for renewing stay-bolts in small numbers would be 15 cents per pound. This is for the simplest cases; if there is any machinery or part to be removed, the cost would be greatly increased. Inasmuch as the cost of labor alone for renewals is nearly three times the cost of the highest priced stay-bolt iron, it would be economical to use a special stay-bolt iron possessing the necessary properties to resist repeated bendings.

The approximate weight of one $\frac{7}{8}$ inch stay-bolt, rough, $7\frac{1}{2}$ inches long, is $1\frac{1}{4}$ pounds.

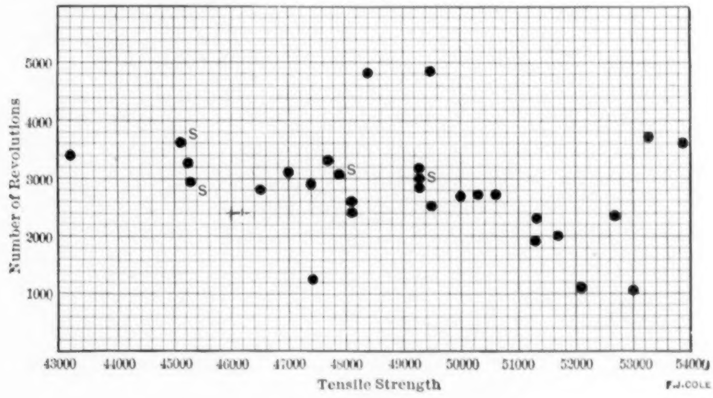

FIG. 160.

The approximate weight of one $\frac{7}{8}$ inch stay-bolt, rough, 12 inches long, is 2 pounds.

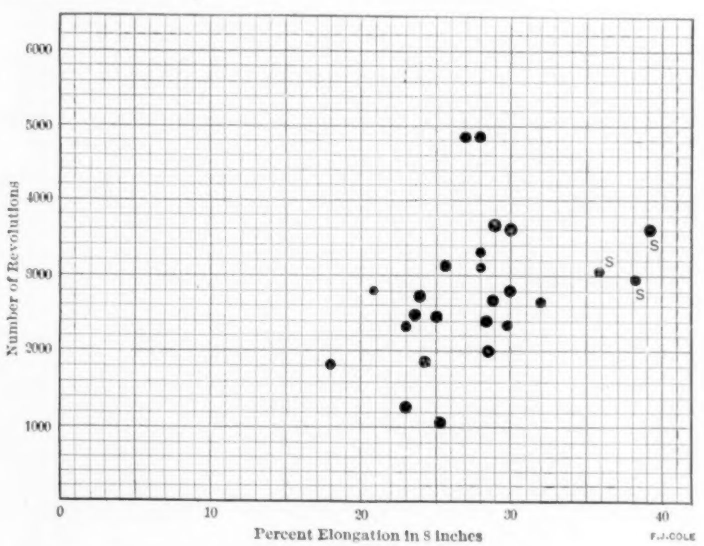

FIG. 161.

The approximate weight of one $\frac{15}{16}$ inch stay-bolt, rough, $7\frac{1}{2}$ inches long, is $1\frac{1}{2}$ pounds.

The approximate weight of one $\frac{15}{16}$ inch stay-bolt, rough, 12 inches long, is $2\frac{3}{16}$ pounds.

The approximate weight of one 1 inch stay-bolt, rough, $7\frac{1}{2}$ inches long, is $1\frac{3}{4}$ pounds.

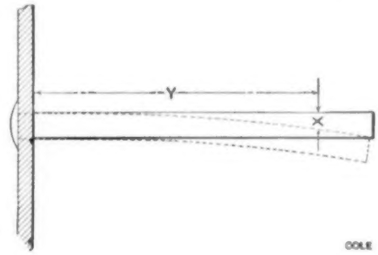

FIG. 162.

The approximate weight of one 1 inch stay-bolt, rough, $12\frac{1}{2}$ inches long, is $2\frac{6}{16}$ pounds.

In the photographs of the test specimens, the one at the top is a piece 12 inches long, threaded and doubled over; that in the centre, a piece pulled apart in the usual manner, to determine the

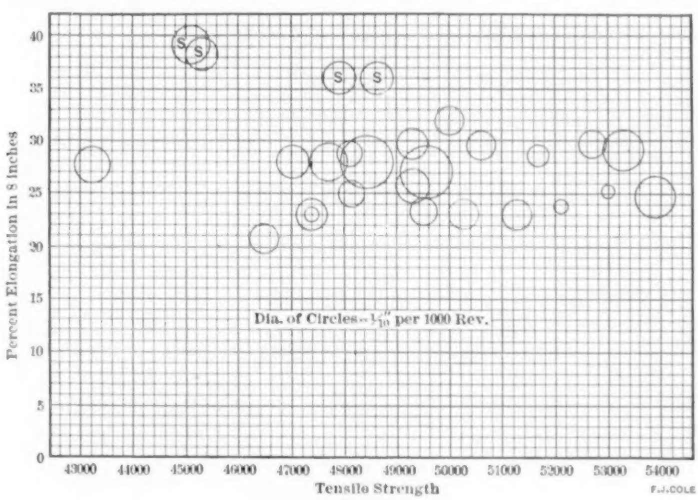

FIG. 163.

elongation and tensile strength, and at the bottom are shown the pieces broken by bending or "wiggling" in the special machine.

The results of the tests are plotted in Figs. 160, 161, and 163.

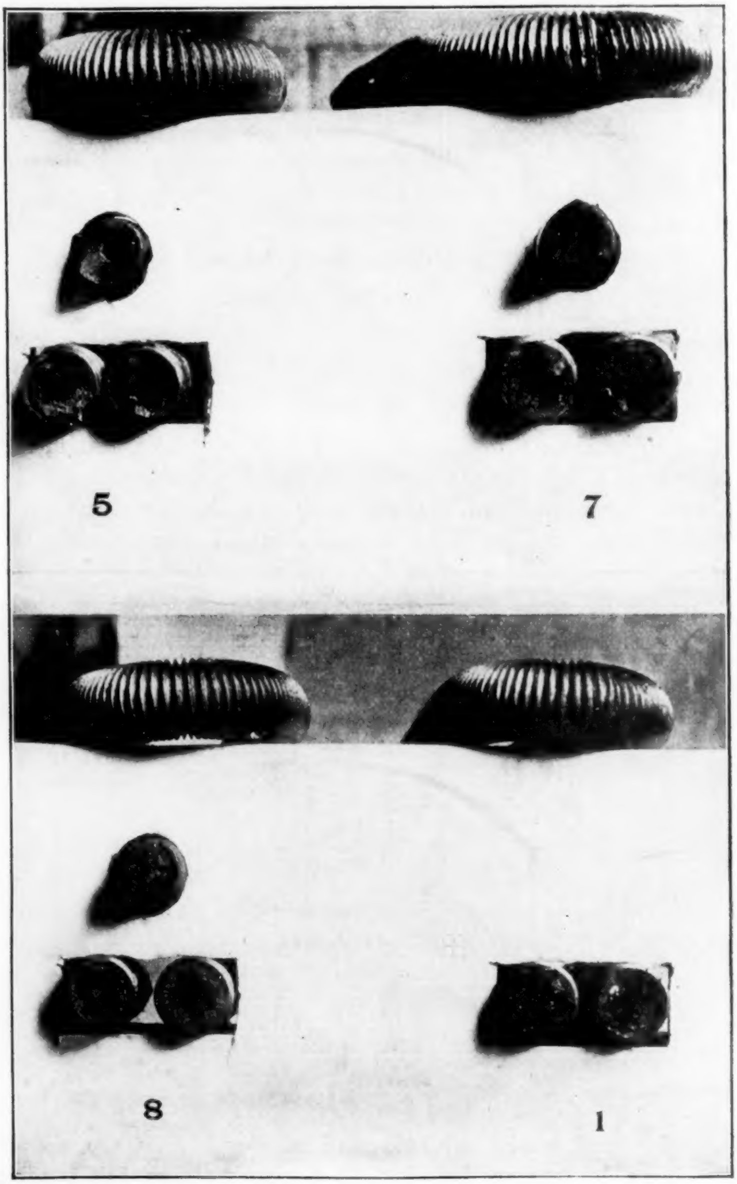

Fig. 164.

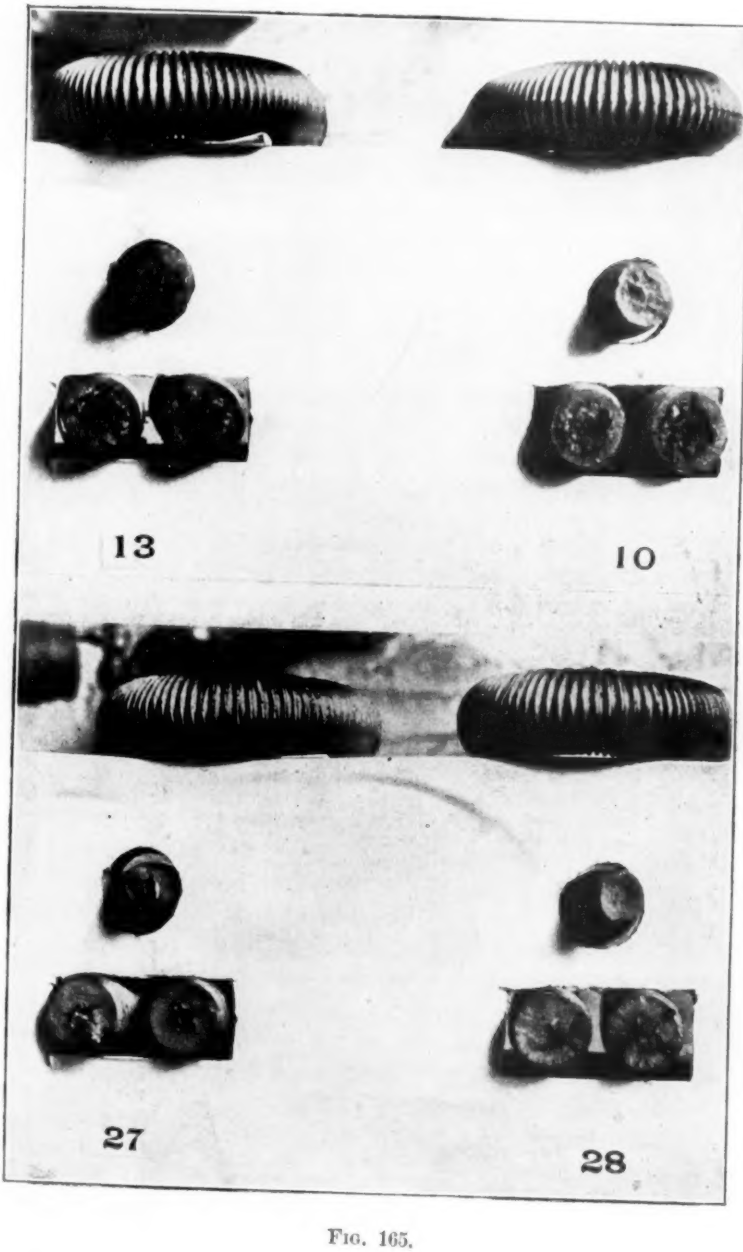

Fig. 165.

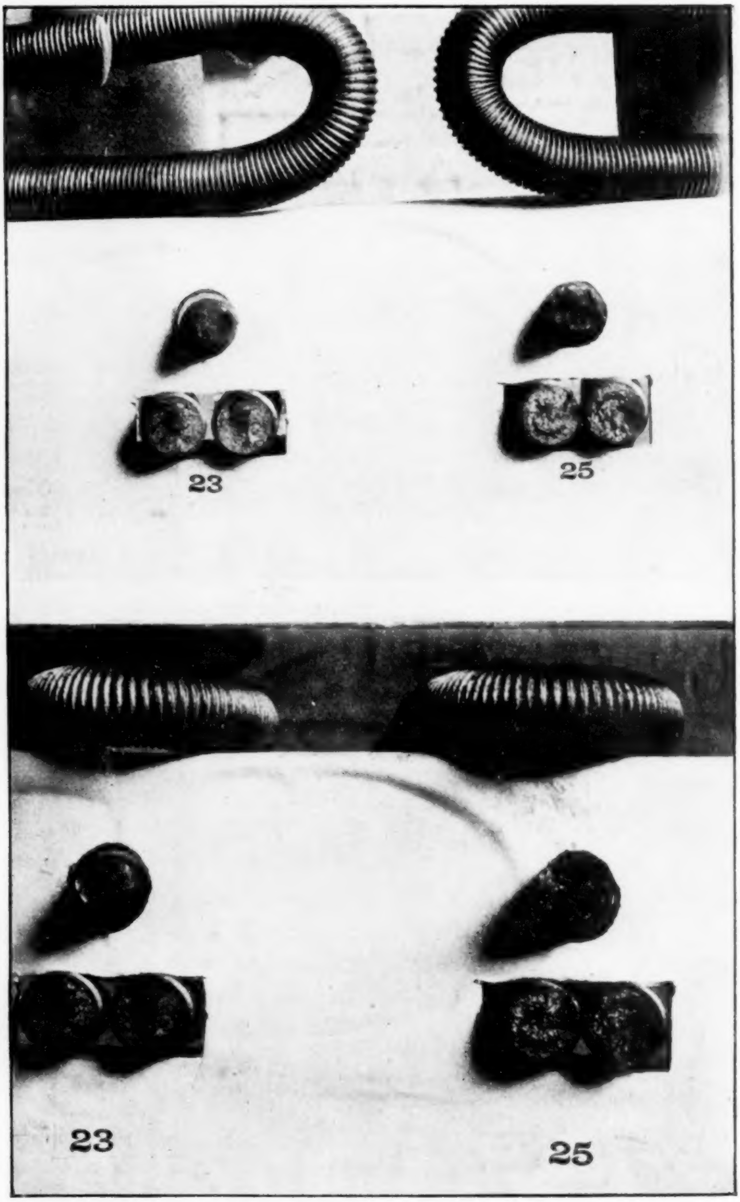

FIG. 166.

A careful study of these shows that the best results were obtained from an iron having an ultimate strength of 48,000 to 49,500 pounds, with an elongation of 28 to 30 per cent. in 8 inches.

If it were possible to make the stay-bolts of sufficient length to allow for the maximum movement of the fire-box, so as to bend them within their elastic limit, without producing a permanent set, their life would be increased to a remarkable extent. This is shown in Fig. 162; the dotted line is assumed to represent, in an exaggerated form, the curve of the bolt, when bent within the elastic limit, or the deflection, which would require several million repetitions before fracture would take place.

Let X represent this movement at a distance Y, it is evident, then, that if the length, Y, is decreased, the bending movement will be increased so that fracture will occur with a smaller number of movements. With a constant amount of movement, the decrease of length can so intensify the bending stress that fracture will occur after a few thousand repetitions of the force, produced by the expansion and contraction of the boiler.

Specimen No.	Bending Test.	Tensile Test.					
	No. of Revolutions.	Nominal Diameter. Inches.	Area Sq. Inches.	Strength per Sq. Inch.	Elastic Limit.	Elongation per cent. in 8 Inches.	
1	2,296	$\frac{7}{8}$	.6013	51,220	35,200	22.75	Good wrought iron, 1.6c. per lb.
1	2,154	"	.6013	51,550	34,900	23.25	
1	2,437	"					
1	2,319	"					
1	2,252	"					
1	2,453	"					
Average	2,319	....	....	51,385	35,050	23.00	
2	2,459	$\frac{7}{8}$	.6054	49,800	32,200	23.75	Same iron as No. 1.
2	2,235	"	.6041	49,330	33,100	23.12	
2	2,776	"					
2	2,785	"					
2	2,245	"					
2	2,629	"					
Average	2,522	....	....	49,565	32,650	23.43	
3	3,386	$\frac{7}{8}$	.6027	46,190	30,500	20.0	Same iron as No. 1.
3	1,226	"	.5972	46,880	28,400	21.5	
3	4,453	"					
3	2,300	"					
3	2,240	"					
3	3,260	"					
Average	2,811	....	....	46,535	29,450	20.75	
4	2,546	$\frac{7}{8}$	.6000	50,000	34,100	26.62	Same iron as No. 1.
4	2,691	"	.6000	50,660	33,000	21.00	
4	2,873	"					
4	2,636	"					
4	2,754	"					
4	2,820	"					
Average	2,720	....	....	50,330	33,550	23.81	
5	2,028	$\frac{7}{8}$	.588	61,460	44,200	17.1	Not made for stay-bolts. Ordinary merchant mild steel.
5	1,870	"	.588	61,730	44,200	19.0	
5	1,882	"					
5	1,553	"					
5	1,869	"					
5	2,008	"					
Average	1,868	....	....	61,595	44,200	18.0	
6	1,046	$\frac{7}{8}$	.586	53,240	36,500		Not made for stay-bolts. Ordinary merchant bar iron.
6	1,289	"	.592	52,600	35,400	26.75	
6	1,012	"	.588	53,200	36,600	24.25	
6	832	"					
6	1,028	"					
6	1,140	"					
Average	1,058	....	....	53,013	36,200	25.33	
7	1,615	$\frac{7}{8}$	.597	51,340	37,270	24.25	Same as No. 6.
7	1,707	"					
7	1,746	"					
7	2,136	"					
7	2,147	"					
7	1,824	"					
Average	1,863	....	....	51,340	37,270	24.25	

Specimen No.	Bending Test.	Tensile Test.					
	No. of Revolutions.	Nominal Diameter. Inches.	Area Sq. Inches.	Strength per Sq. Inch.	Elastic Limit.	Elongation per cent. in 8 Inches.	
8	676	$\frac{7}{8}$	.629	53,050	33,070	28.50	Imported stay-bolt iron, 6c. per lb.
8	1,715	"	.629	52,460	33,500	31.25	
8	1,569	"					
8	2,165	"					
8	2,055	"					
8	5,941	"					
Average	2,354	....	....	52,755	33,285	29.87	
9	1,873	$\frac{7}{8}$	.624	51,600	34,900	30.00	Same as No. 8.
9	2,213	"	.622	51,800	33,400	27.25	
9	2,865	"					
9	2,850	"					
9	1,114	"					
9	1,174	"					
Average	2,015	....	...	51 700	34,150	28.62	
Gen. Ave.	2,185	....	....	52,228	33,718	29.25	
10	2,950	$\frac{7}{8}$	.597	50,580	33,830	28.12	Stay-bolt iron, 4$\frac{1}{2}$c. per lb.
10	2,532	"	.594	50,690	34,090	31.12	
10	2,721	"					
Average	2,734	....	....	50,635	33,960	29.62	
11	3,790	$\frac{7}{8}$	.603	53,530	36,930	28.0	Same as No. 10.
11	3,076	"	.603	53,070	33,990	30.25	
11	4,148	"					
11	3,437	"					
11	4,051	"					
Average	3,700	....	....	53,300	35,460	29.12	
Gen. Ave.	3,217	....	....	51,968	34,710	29.37	
12	3,150	$\frac{7}{8}$	.636	47,640	31,760	28.0	Special stay-bolt, 4$\frac{3}{4}$c. per lb.
12	2,655	"	.636	47,900	31,800	28.0	
12	2,734	"					
12	2,021	"					
12	3,316	"					
12	4,332	"					
12	2,785	"					
12	4,986	"					
Average	3,322	....	....	47,770	31,780	28.0	
13	3,042	$\frac{7}{8}$	.643	48,450	29,800	25.75	Same as No. 12.
13	2,218	"	.624	50,240	35,100	25.50	
13	3,779	"					
13	3,785	"					
13	2,966	"					
13	3,402	"					
13	3,241	"					
Average	3,148	....	....	49,345	32,450	25.62	
Gen. Ave.	3,235	....	....	48,559	32,115	26.81	

Specimen No.	Bending Test. No. of Revolutions.	Tensile Test. Nominal Diameter. Inches.	Area Sq. Inches.	Strength per Sq. Inch.	Elastic Limit.	Elongation per cent. in 8 Inches.	
23	3,571	$\frac{7}{8}$	.584	50,000	29,400	32.	Special stay bolt iron, 6c. per lb.
23	2,757	"	.578	50,000	29,200	32.	
23	2,170	"					
23	2,533	"					
23	2,335	"					
Average	2,673	....	....	50,000	29,300	32.	
24	2,620	$\frac{7}{8}$	.581	49,600	29,200	30.	Same as No. 23.
24	2,913	"	.581	49,100	27,600	29.75	
24	2,202	"					
24	3,794	"					
24	3,334	"					
24	2,129	"					
Average	2,832	....	....	49,350	28,400	29.88	
Gen. Ave.	2,753	....	....	49,675	28,850	30.94	
25	4,027	$\frac{7}{8}$	.6366	43,150	24,000	27.75	Swedish iron, $2\frac{1}{4}$c. per. lb.
25	4,422	"	.6361	43,230	23,900	27.62	
25	3,082	"					
25	2,712	"					
25	2,783	"					
25	2,081	"					
25	2,906	"					
25	4,256	"					
25	4,428	"					
25	2,682	"					
Average	3,338	....	....	43,190	23,950	27.68	
26	2,619	$\frac{7}{8}$	.6000	45,330	30,660	35.75	Mild rivet steel.
26	3,443	"	.6000	45,400	30,830	40.87	
26	3,234	"					
26	2,702	"					
26	2,095	"					
26	3,586	"					
Average	2,947	....	....	45,365	30,745	38.31	
27	3,792	$\frac{7}{8}$	.6000	45,350	31,660	40.75	Same as No. 26.
27	3,808	"	.6000	45,000	30,830	37.75	
27	4,301	"					
27	3,365	"					
27	2,799	"					
Average	3,613	...	....	45,175	31,245	39.25	
Gen. Ave.	3,280	....	....	45,270	30,995	38.78	
28	1,755	$\frac{7}{8}$	.6082	47,920	32,000	36.50	Mild rivet steel, 2c. per lb.
28	3,619	"	.6096	47,900	34,100	36.50	
28	3,546	"					
28	3,313	"					
28	2,591	"					
28	3,627	"					
28	2,958	"					
Average	3,058	....	....	47,910	33,050	36.00	

Specimen No.	Bending Test. No. of Revolutions.	Tensile Test. Nominal Diameter. Inches.	Area Sq. Inches.	Strength per Sq. Inch.	Elastic Limit.	Elongation per cent. in 8 Inches.	
29	3,194	$\frac{7}{8}$	.6068	49,350	31,970	35.75	Mild rivet steel, 2c. per lb.
29	3,040	"	.6054	49,220	29,730	36.37	
29	3,337	"					
29	2,969	"					
29	3,415	"					
29	2,350	"					
29	2,790	"					
Average	3,014	....	....	49,285	30,566	36.06	
Gen. Ave.	3,036	....	....	48,598	31,808	36.03	
30	2,259	$\frac{7}{8}$	.6013	48,390	31,500	25.0	Good wrought iron, 1.6c. per lb.
30	2,636	"	.6054	47,900	31,000	25.0	
Average	2,448	....	....	48,149	31,250	25.0	
32	3,780	$\frac{7}{8}$	.6013	48,390	31,500	25.0	Iron, 1.6c. Same as No. 30, $\frac{7}{8}$ in. diameter. Reduced in centre to $\frac{11}{16}$ inch.
32	3,059	"	.6054	47,900	31,000	25.0	
32	3,065	"					
32	2,823	"					
32	2,647	"					
32	1,902	"					
32	2,091	"					
32	2,234	"					
32	2,582	"					
Average	2,687	....	....	48,149	31,250	25.50	
18	1,493	1	.786	53,470	32,800	22.00	Good wrought iron, 1.6c. per lb. Not reduced.
18	719	"	.786	50,760	32,900	25.75	
Average	1,106	....	....	52,115	32,850	23.88	
19	2,326	1	.786	53,470	32,800	22.00	Same as No. 18. Reduced in centre to $\frac{13}{16}$ inch.
19	2,635	"	.786	50,760	32,900	25.75	
Average	2,481	....	....	52,115	32,850	23.88	
20	938	....	.786	53,470	32,800	22.00	Same as No. 18. Reduced in centre to $\frac{3}{4}$ inch.
20	931	....	.786	50,760	32,900	25.75	
Average	935	....	....	52,115	32,850	23.88	
21	1,139	....	.786	53,470	32,800	22.00	Same as No. 18. Reduced in centre to $\frac{11}{16}$ inch.
21	1,208	....	.786	50,760	32,900	25.75	
Average	1,174	....	....	52,115	32,850	23.88	
Gen. Ave.	1,424	....	....	52,115	32,850	23.88	
33	3,481	1	.7775	47,850	32,400	27.88	Stay-bolt iron "ordinary," 3c. per lb.
33	2,629	"	.7791	48,390	33,400	29.75	
33	2,177	"					
33	2,307	"					
33	2,647	"					
33	1,894	"					
33	2,412	"					
33	2,379	"					
33	2,093	"					
Average	2,447	....	....	48,120	32,900	28.81	

Specimen No.	Bending Test.	Tensile Test.					
	No. of Revolutions.	Nominal Diameter. Inches.	Area Sq. Inches.	Strength per Sq. Inch.	Elastic Limit.	Elongation per cent. in 8 Inches.	
33x	688	1	.7729	47,000	32,900	22.23	Iron, 1.6c per lb.
33x	1,829	"	.7822	47,810	32,200	23.75	
Average	1,259	....	....	....	32,550	22.99	
35	2,859	1	.7729	47,000	32,900	22.23	Iron, 1.6c. per lb. Reduced in centre to $\frac{13}{16}$ inch.
35	2,656	"	.7822	47,810	32,200	23.75	
35	3,189	"					
35	3,380	"					
35	3,247	"					
35	2,321	"					
Average	2,942	....	....	47,405	32,550	22.99	
38	3,435	$\frac{7}{8}$	.6138	53,926	35,516	29.9	Stay-bolt iron "special," $4\frac{3}{4}$c. per lb.
38	4,226	"					
38	3,170	"					
Average	3,610	....	....	53,926	35,516	29.9	
37	3,747	$\frac{7}{8}$	.635	47,000	30,710	28.1	Stay-bolt iron "ordinary," 3c. per lb.
37	2,340	"	.622	....	31,550		
37	2,407	"					
37	2,931	"					
37	4,319	"					
37	3,021	"					
37	3,523	"					
37	2,652	"					
Average	3,118	....	....	47,000	31,730	28.1	
39	4,333	$\frac{7}{8}$	.6096	49,700	....	28.13	Stay-bolt iron, 3c. per lb.
39	5,397	"	.6110	49,400	....	26.00	
39	6,702	"					
39	4,304	"					
39	4,447	"					
39	3,519	"					
39	7,305	"					
39	1,698	"					
39	4,842	"					
39	4,396	"					
39	6,633	"					
Average	4,871	....	....	49,550	....	27.06	
40	6,765	$\frac{7}{8}$	.6068	48,800	....	30.00	Same as No. 39.
40	3,079	"	.6082	48,000	....	26.25	
40	3,909	"					
40	4,195	"					
40	5,375	"					
40	3,105	"					
40	4,550	"					
40	2,841	"					
40	9,610	"					
Average	4,825	....	....	48,400	....	28.12	
Gen. Ave	4,848	....	....	48,975	....	27.59	

DISCUSSION.

Mr. Spencer Otis.—I have read Mr. Cole's article on a bending test for stay-bolt iron with much interest, and discuss it only because a number of tests witnessed, and a number of others of which I have a record, would seem to agree very closely with some of Mr. Cole's conclusions, and very materially with others.

In the first place, let me say the number of broken stay-bolts has been increasing rapidly on all the Western railways with which I am acquainted. I saw a record only a few days ago which showed over three times as many broken stay-bolts in 1897 as in 1894, and this for a given number of locomotives.

I think the reasons generally assigned agree with those given by Mr. Cole; but how much can be attributed to the bending action and how much to increased tension caused by higher pressure is uncertain. The manufacturers of stay-bolt irons are undoubtedly trying hard to make an iron which will stand this service, and a number of the railway companies are experimenting to find out what irons will give the best service and what qualities such an iron must possess. Some of them are simply trying in actual service several different makes of iron known to be good under practically the same conditions, and keeping a record of results. Others are adding to this a record of tensile strength, elastic limit and elongation of each iron used. A few, however, are adding to all of this a vibration test. I have a record of about one hundred and fifty specimens tested on a machine very similar to the one Mr. Cole describes; instead, however, of using a tension of 2,400 pounds, only 1,000 pounds was used, and in some of them no tension at all. The number of vibrations, as shown by these tests, were uniformly higher than those mentioned by Mr. Cole, and, too, in some cases with apparently about the same quality of iron as Mr. Cole used, the number or vibrations were very much greater.

After reading his results I am inclined to give increased tension more credit for broken stay-bolts than I had done.

Taking the averages of experiments with which I am acquainted, it would seem:

1. That the best American stay-bolt irons would stand fully as good a vibration test as the same grade of foreign irons.

2. That the piled irons, with grain at a right angle to the line of

vibration, stand this test better than either bloom irons or irons piled with the grain in line with the vibration.

3. On the basis of the number of vibrations withstood, the high-grade irons, those made especially for stay-bolts, are very much cheaper than ordinarily good iron.

4. That the ordinary tests give very little indication as to how a given iron will stand a vibration test; for instance, the average of some twenty tests of each of two irons is:

	Tensile Strength.	Elongation in 8 Inches.	Elastic Limit.	Vibrations with 1,000 lbs. Tension.
No. 1 . . .	52,000	25%	26,600	89,170
No. 2 . . .	51,400	28%	26,210	37,470

5. By reducing the shank of stay-bolts to a shade below the bottom of the thread, you very decidedly increase the number of vibrations it will stand. I think the average was about double what the same iron would stand when threaded the full length.

6. That a tell-tale hole $\frac{1}{8}$ inch diameter clear through the bolt reduces the number of vibrations which it will stand, and that a larger hole does so very materially.

I find there are several roads which have been using a tell-tale hole $1\frac{1}{8}$ inches to $1\frac{1}{2}$ inches deep which are beginning to fear reducing the shank of stay-bolts is going to cause them to break near the centre of bolt and beyond the reach of the short tell-tale hole.

To sum up, it seems to me there is a good deal to learn about stay-bolts and stay-bolt iron, and if in order, I should like to make a motion that a committee be appointed to collect all the information possible on this subject, and report progress at our next meeting.

Mr. Gus. C. Henning.—I would like to call attention to the fact that the method of holding the bolts shown by the machine does not represent the stay-bolt as held in the boiler. The stay-bolt is held for a short distance at either end. And then the position of one sheet changes with reference to the other. The stay-bolt during this change of position of sheets does not assume the curve Fig. 162, but being held at both ends, provided the sheets work vertically only, as may be in the case assumed, the position as Fig. 168, in which case the strain on the bolt at the surface of the sheet is very much greater than if that were simply bent. It would be just twice as much, because this is simple flexure and this is contra flexure. Now that is not the only way the boiler works. The normal condition of the stay-bolt is like in

Fig. 167, assumimg that there are no initial strains. Initial strains are very injurious to stay-bolts, perhaps more to them than to any other part of the boiler. The next position, is like that in Fig. 168, that the one sheet remains in its position, while the other one buckles at one point or other for various reasons. The other position is that the other sheet is vertical and the reverse of Fig. 168, but which produces the same result. Then we have the other conditions that the plate between stay-bolts bulges and produces the effect as in Fig. 169. Stay-bolts are constantly revolving or changing their condition on account of the change of the shape of the plates between the stay-bolts. This machine does not repeat all these changes of strain. This is particularly noticeable

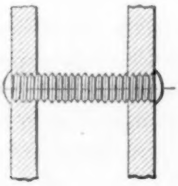

Fig. 167.

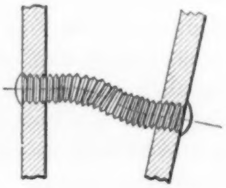

Fig. 168.

Fig. 169.

in the stay-bolts where the thread has been cut away, and therefore the results are not such as we would expect. Similar tests have been made abroad—I don't know whether they have been made here—and results which are more in accordance with our present knowledge of the behavior of the stay-bolts than is shown in the paper. Fig. 162 in the paper shows a curve which is obtained only when the bolt is held at one end and free at the other. The actual conditions are, however, as shown in Figs. 168 and 169, the centre lines of stay-bolts showing the curves of flexure, and under these conditions the stress on threads at sheets is just twice as great as that assumed by the author.

Mr. Otis.—I think Mr. Henning is correct, and that the actual service of the stay-bolt is very much more severe than is reproduced in a vibrating machine. But it seems to me that the iron which will stand a vibrating machine well would also stand the service of which you speak—that the same qualities would be required

in both cases, although the tests you propose would be very much more severe and nearer actual service.

Mr. Henning.—I would like to qualify that. If the iron is all right to resist these strains, it may not be all right to stand the cold hammering. The cold hammering may produce crystallization which runs quite into the bolt through the sheet. Say the sheet is $\frac{3}{8}$ of an inch thick, the ordinary thickness for crown sheets, the crystallization runs back into the body of the bolt. I have recently had occasion to break a lot of them. The iron may be all right to resist a strain, but that is not what is wanted; an iron is wanted which will resist the fire, an iron which will not crystallize under the cold riveting to which a stay-bolt is subjected; an iron which is not made brittle or injured, because of its seams or other defects by cutting the threads, or an iron which is able to resist all these strains of torsion, of tension and flexion.

Mr. Jno. E. Sweet.—In the June number of *Locomotive Engineering* there appears an article on stay-bolts, written before this paper appeared, and I noticed the paper confirms the assumption that there is plenty of tensile strength in the bolt, but not enough to stand the bending strain, and that the real destruction comes from the bending. This idea has occurred to me. We all know that four pieces of half inch square iron are as strong in tensile strength as one inch square, and the four pieces will stand four times as much bending as the one. The suggestion is made to split along the middle into four quarters. Thus you will see we have a bolt which will stand a sufficient tensile strain and more bending.

Another way to carry out the same idea would be to have the iron rolled in the form of a quarter of a circle, so that when four pieces were put together they would form a round a little larger than the outside of the thread. After the ends were welded and swedged to size, the centre could be heated to a forging heat and drawn down to the size of the bottom of the thread.

This would be a more expensive construction, but it would leave the bolt as strong in tension as the rated one, and it would be free to bend four times as many times before rupture. Another plan suggested by Mr. S. W. Baldwin was to roll a quarter of a circle in section, cut it off too long, but have sections of such a size that when the four pieces were put together they would be the diameter of the bolt at the bottom of the threads, and in welding upset the ends to make them large enough for the

threads. This was his suggestion, and I guess a better plan.* Now, if I had fire-boxes to make I would try the experiment, and I would also try another experiment, though I do not know but that it has been tried. From what I have read about the difficulty of getting the proper pitch on stay-bolts, I infer there is trouble in getting them to enter the inside sheet after they run through the outside sheet. Is there much trouble about that?

Mr. Otis.—There is no trouble about that.

Mr. Sweet.—Then the suggestion for a remedy would not be in order.

Mr. Henning.—The two sheets are so flexible that with a little bit of forcing the thread will enter, but it does not leave the sheets unstrained, and this is one of the causes why the shells and fire-boxes do not expand uniformly. If the beginning of the thread is on the top in both places, and there is an even number of threads, it will enter exactly, but if the threads miss each other by half a diameter, then those sheets will be separated and the sheet will be bent. Now, the next one may be just exactly the reverse, and the result is that the adjoining part is bent in the opposite direction. Sheets are not planes, as they are supposed to be, and the change of shape is what bends the stay-bolts as much as anything else.

Mr. Sweet.—Do you think that does really amount to much—that if you are sure that there was no strain it would be better, or is it a fact that that strain does so little harm that it is not necessary to take it into account?

Mr. Henning.—Believing in the highest class of work for boilers, I always believe that it ought to be tapped right through, and that spreaders should be put in the water space which can be removed when stay-bolts have been put in. If that is the case then the boilers will behave very much better than they do now.

Mr. Otis.—I think the tubes would cover that very well in a locomotive. The tap is put through and taken out, and the bolts

* To meet the conditions described by Mr. Henning, where it is assumed that the plates change from parallel, I have thought of the following scheme which would meet the difficulty and otherwise improve the quartered stay-bolt. After the forging is finished as described, twist the middle or quartered part of the bolt, one-half revolution. Neither quarter will then be strained any more than any other quarter, however much the plates may be distorted. The section of the bars might have to be modified slightly to meet the change of shape due to twisting, and this twisting, if done right-handed, would avoid the danger of the bolts twisting when screwed in.

put in the same head and then capped up much straighter and put in very nearly correct, I think, than by the old way of doing by hand.

Mr. Henning.—If you tap it through, and the threads of the bolt do not exactly enter the threads of the sheet, then it will take a whole revolution of the bolt before it springs the second time. Then the flexure is very much greater than it is in the case that I described, in which I simply assume that the thread does not exactly match the thread in the other sheet.

Mr. Sweet.—Do you mean to say that even if the stay-bolt was of the proper pitch still they would get a complete revolution before they got it in?

Mr. Henning.—It might be two or three, because they might burr the thread in the sheet or on the stay-bolt and then simply keep turning until it enters.

Mr. Sweet.—I would use a long taper tap, and make the small end of the thread on one end larger than the large end of the thread on the other, and it would be sure to enter, and enter easily, because, being V threads, it could not help but enter correctly. There may be some objection to that, but it occurs to me it is possible. In renewing a stay-bolt I do not know whether they have to tap out the hole or not. If they do, running the tap a little farther would correct the hole. If they have to put in a $\frac{7}{8}$ stay-bolt when a $\frac{3}{4}$ was in originally, they have to increase the hole a whole eighth of an inch.

Mr. Henning.—The same difficulty you have in entering a bolt into a nut. Some men can always enter a bolt the first time they come to the thread. Others turn that bolt half a dozen times before it enters.

*Mr. Francis J. Cole.**—The greater number of vibrations obtained in other bending tests is due principally to the fact that the fixed end, when screwed into a thin plate (say $\frac{3}{8}$ of an inch thick), is not held rigidly. This is partly owing to the spring of the plate and partly to the bolt becoming slightly loosened by the repeated vibrations, or from lack of a tight fit at first between the screw threads. It can also be accounted for by the lower tension of 1,000 pounds, instead of 2,400 pounds—the latter representing more nearly the stress in actual service. Stay-bolts in locomotives always break at the outside plates, which are thicker and cooler,

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* Author's closure, under the Rules.

and rarely, if ever, under normal conditions, at the thinner box plates. This, in a measure, answers the criticism that the machine does not bend the bolts as they are bent in the boiler. A superficial investigation of the actual conditions existing might lead one to imagine that the bolt should be held rigidly at both ends, and vibrated by moving in parallel planes. Under these conditions the fracture would be as likely to occur at one end as the other. As a matter of fact, one end, when screwed into a boiler, is held much more rigidly than the other, the thinner and hotter fire-box plates permitting a slight movement or buckling to take place, relieving the bending stress at that end. The important point in bending tests of this description is to get comparative results of different makes of material under similar conditions of bending and tension stresses. The known stresses, such as that due to the direct steam pressure, forcing the plates apart, should, evidently, be taken at the actual figures, rather than at 60 or 75 per cent. below the real amount. The injury caused by cold hammering in riveting over the ends does not, to my mind, extend through plates $\frac{1}{2}$ to $\frac{5}{8}$ inch thick, and perceptibly weaken the material. If this were the case, the injury would manifestly be greatest in the $\frac{5}{16}$ inch plates used in fire-boxes, and, consequently, the life of these bolts would be much shorter than in the heavier plates. This we know, positively, is not the case. If it were true, increasing the thickness of the outer plates to an extent somewhat more than the depth to which the influence of the cold hammering extends would prevent all injurious effects and prolong the life of the bolts. As a matter of fact, however, it is well known that the tendency to break seems to increase with the thickness of the plates.

Since the tests were made, nickel steel has been used in a few instances for stay-bolts, but time enough has not elapsed to know definitely what results will be obtained. It is to be regretted that comparative tests of the various makes of hollow stay-bolts and of nickel steel could not be made on the machine under the same conditions.

DCCLXXIX.*

THE RELATIONS BETWEEN THE PURCHASER, THE ENGINEER, AND THE MANUFACTURER.

BY WILLIAM H. BRYAN, ST. LOUIS, MO.
(Member of the Society.)

WHEN an engineering structure of magnitude is to be erected what general plan of procedure should be followed in order to insure that the finished work shall be best adapted for the intended purpose, and shall involve the minimum investment of capital consistent with proper construction, and the minimum cost of operation and maintenance?

In the erection of buildings the precedent of placing the work in the hands of a skilled architect has long since become well established. In civil engineering, the construction of railways, bridges, and roofs is universally intrusted to engineers. In the newer branches of mechanical and electrical engineering, however, it has only recently become the practice in this country to engage consulting engineers. The principal reason for this has been that there have been heretofore but few specialists who have devoted their attention exclusively to this class of work. The few well-trained men in these fields early connected themselves with manufacturing or contracting companies, or entered into these branches of work on their own responsibility. The natural disinclination of the purchaser to ask for expert advice from an engineer—however competent and experienced—who is known to be interested in the manufacture or sale of some specialty, and whose opinion is not unnaturally open to the suspicion of bias, left him no course but to proceed on his own responsibility, with results which were often as unsatisfactory to the manufacturer as to himself.

This situation has, however, in a large degree changed, owing to the large number of excellent engineering schools, and the

* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

very thorough courses of theoretical and practical training which are there given. These, coupled with the large number of trained and experienced men who have been connected with prominent manufacturing and constructing companies, and with the installation and operation of large plants, have now rendered available the services of many men of thorough technical training, supplemented by years of practical experience in actual construction. Many of these have no connection with the manufacturing, selling, and contracting interests, and their judgment is not, therefore, open to the suspicion of bias in favor of or against any special manufacturer.

It is becoming more and more the custom, therefore, to place the same confidence in the consulting mechanical and electrical engineer which has long been reposed in the architect and civil engineer. He is called in at the earliest stages of the development of the enterprise, for advice as to the general outline and arrangement of the scheme, its probable cost, the expense of operation and maintenance, and the returns which may be expected from the investment. He makes a preliminary reconnoissance and report, giving this data. If these are approved, he then makes a more detailed study of the problem, mapping out the general scheme more definitely, selecting the particular system or type of apparatus best suited to the local conditions of service, and preparing general plans and specifications. These he accompanies with more detailed estimates of cost. When these are approved by his principals, proposals are asked for, and when received, the engineer assists the purchaser in canvassing and comparing them, and in selecting that proposal—not necessarily the lowest—which seems best to meet the requirements of the work in hand.

The engineer then assists his clients in drawing up the final contracts, supervises the work during construction, and makes such final inspections and tests at completion as are necessary to determine whether the specifications have been complied with.

This has long been the accepted custom in England, where the same difficulty of securing competent and unbiassed engineers has not been encountered. No trouble has been met with in that country in applying the same rules to these branches of engineering which are universally followed in other fields.

As might be expected in any new department of engineering, however, the relations between the purchaser, the engineer, and

contractor have not always been harmonious. The manufacturer frequently feels that he has been imposed upon ; the engineer is often hampered by incompetent or unscrupulous contractors, and between the two the purchaser himself is sometimes at a loss for a proper solution of the difficulty. While it is true that most contracts of this character are carried through satisfactorily, it must be admitted that misunderstandings are more frequent than they should be.

The discussion of these differences has recently taken tangible form both in this country and England. In the latter country, the manufacturers and engineers recently met, and succeeded in agreeing upon a number of standard clauses for specifications, which removed many of the objections and criticisms from both points of view. It has been suggested that this work of preparing standard specifications would come properly within the province of the national engineering societies, but if these bodies do not take the matter up, something might be accomplished by the engineers and manufacturers getting together for mutual exchange of views, as was done in England.

The present misunderstandings may be traced to a few serious causes: In the first place, the mechanical and electrical fields of work have, unfortunately, been embarrassed by too great a number of incompetent and inexperienced manufacturers and contractors, poorly equipped for good work, and with but limited intelligence and skill. To these have been added a more than ordinarily large percentage of contractors who are not altogether scrupulous as to their methods, and whose object is to finish the work in almost any sort of shape which will pass muster. These incompetent, inexperienced, and unscrupulous contractors—though relatively few in number—have detracted from the good reputation of work of this character, and have forced upon the consulting engineer the necessity of inserting in his specifications the most rigid requirements as to the character of workmanship and material, inspections and tests, which would be unnecessary if it were certain that the work would be awarded to contractors of established reputation, ability, and skill.

Furthermore, it has been found that some manufacturers are slow to adapt their designs and patterns to advanced and improved practice. Experience having shown the clear and decided superiority of certain designs, the engineer is justified in

embodying them in his specifications, in spite of the fact that some manufacturers will attempt to force the continued use of antiquated forms.

Again, the manufacturers are often careless in making guarantees. Some of them do not hesitate to meet any desired figures, if a competitor does so. Often they will oblige themselves to do what is impossible with the type of machinery they offer, and trust to luck, or careless inspection or testing, to get the work accepted and paid for.

The grievances of the manufacturers have recently taken shape in papers and discussions in the electrical press, and may be briefly summarized as follows:

First.—That the engineer appears unwilling to receive suggestions or advice from the manufacturers, as such action might detract from the "dignity" of his position, and that specifications, therefore, often contain many annoying and expensive provisions, sometimes impossible of fulfilment.

Second.—That the engineer does not always familiarize himself with the facilities and standards of the manufacturer, and thus sometimes calls for special designs which can only be made, if at all, at greatly increased expense; whereas standard apparatus would frequently answer the purpose equally well.

Third.—That if the manufacturer is required to guarantee results, he should not be hampered as to details of design or construction. In other words, the consulting engineer should not tell the manufacturer how he should build his machine, but simply hold him responsible for results.

To these it may be answered, that no harm can be done by full and free consultations between the manufacturer and the engineer. They have a common object in view, namely, the securing of the best results. It is natural that the engineer should reserve unto himself a due degree of dignity, but he should not let this characteristic stand in the way of the best service in the interest of his clients.

The demand for special machinery, however, presents greater difficulties. It should be remembered that electrical developments have been so rapid in recent years—and with them the construction of special steam engines and appliances—that a large percentage of the work has necessarily been special. Furthermore, this condition must continue, for the reason that the methods of generating and distributing electricity on a

large scale, over wide areas, for endless varieties of purposes, have by no means reached uniformity of practice or system, and are not likely to very soon. The necessity for special machinery will, therefore, remain with us indefinitely, and will continue to cover a large percentage of our work. We must not lose sight of the fact that to attempt to carry the idea of standards too far will surely result in hindering improvements and stifling progress.

I do not desire to be understood, of course, as decrying the use of standard apparatus for that large and increasing percentage of cases for which it is eminently well adapted. The manufacturers deserve great credit for reducing their machines for different classes of service to standards, and the engineering profession is under many obligations to them for doing so in so thorough and excellent a manner. The reduced cost of standard apparatus; the fact that in using it one follows precedent; that repairs can be more quickly and more cheaply obtained, and that, when secured, the different parts are actually interchangeable, and will fit; and the further fact that standard machines can usually be secured in less time, being frequently carried in stock—all these are points of tangible advantage which no conscientious engineer can afford to overlook. Standard apparatus, however, is only possible when permanency of type and a reasonably constant demand in large quantities are assured. While it will frequently pay the engineer to modify his plans so as to use standard apparatus, there is a point beyond which he cannot go. In such cases he must use special apparatus more closely adapted to his particular needs. All these points must be given the most thorough consideration, and before requiring special work, the engineer must satisfy himself beyond doubt that his principal's needs can better be supplied in this manner, even at the increased cost, and in spite of the greater risks which always accompany the use of new and untried apparatus.

The contention that when a manufacturer guarantees results he should be allowed to design and build the machine in his own way, may be granted in so far as the guarantee can be made to cover every possible valuable feature. When a reasonable number of manufacturers, however, have adopted certain designs and processes of unquestioned superiority, and where these have an important bearing on the life and relia-

bility of the machine, its freedom from annoying interruptions, and which reduce or avoid the necessity for close and continual attention, it is proper to write the specifications so as to limit competition to machines of this advanced type.

Contractors frequently object to specifications which include a deduction for delay in completing the work, but which allow no extra compensation for finishing the work earlier than the date specified. When it is possible for the purchaser to make use of the plant at the earlier date, this criticism is well founded. It is usually the case, however, that the earlier completion in no way benefits the owner, because other equally important contracts may not be finished, or because the date of leases or contracts for service from the plant cannot be brought forward. The delay of any one contractor, however, might readily cause the purchaser serious loss.

Another objection made by the manufacturer—and one which is not wholly without justification—is the unnecessarily exacting requirements of some specifications, and the annoyance to which they are subjected by the engineers. It is unfortunately true that our profession has been no more fortunate than others in keeping out of its ranks the incompetent and the unscrupulous. These men have brought disgrace upon the profession, and the objection of the manufacturers to being handicapped by them is well founded. There is, however, no reason now why the purchaser—even though absolutely unfamiliar with work in this field—should make a mistake in selecting an engineer, as a very little investigation will enable him to ascertain the character, ability, and experience of the man under consideration.

The engineer stands between the purchaser and the contractor, and while he may sometimes insist upon his client's rights to an extent which may appear unjust, he nevertheless recognizes the purchaser's obligations as well, and will see that his end of the contract is equally well maintained. In this way unreasonable requirements may be avoided, prompt payments secured, and the acceptance and settlement made at the proper time and along reasonable lines.

Unfortunately there are some manufacturers who think the consulting engineer unnecessary, and that the business could be better transacted directly between the manufacturer and purchaser. This would be true if the purchaser were always com-

petent to judge of the relative merits of the different systems of apparatus. Unfortunately the agent of the manufacturer cannot always be trusted implicitly as to recommendations, for two reasons: *First*, he has not the time to give to the detailed study of the problem which the consulting engineer must give in order to make a proper selection; *second*, his recommendations are too often biassed by a desire to sell standard apparatus, or some specialty of his own, which could be used for the work, although less advantageously than something else.

It is here that the engineer serves his client best, in seeing that the proper apparatus is selected, and that it is bought at reasonable figures. The days when the salesman with the glibbest tongue did the most business are fortunately passing away, and the small manufacturer has as good a show to do business with the engineer as one of longer standing, providing his apparatus is clearly the best for the work.

The engineer compares machines on as nearly the same basis as possible. So far as the character of the machine will permit, he requires all proposals to be on the same apparatus. When this is impracticable he specifies capacities, results, and general type or construction, leaving the manufacturers to vary the details in accordance with their own designs and practice. Such proposals, however, should be accompanied by ample data, so that the points of agreement and difference may be clearly brought out. With these data before him the engineer is prepared to analyze the bids, and to make a recommendation based upon merit alone, irrespective of the name-plate which may be attached to the machine.

It is not meant by this that no weight whatever is to be given to long experience and established reputation, as there are many details which cannot be inquired into, and must be left to the manufacturer's judgment. No conscientious engineer, however, will let the mere reputation of a manufacturer carry undue weight.

Early in my own practice I learned that while elaborate and detailed specifications embodying all sorts of unusual and peculiar requirements might impress the non-technical reader, and might even gratify the purchaser, they invariably limited competition, and led to excessive prices and annoying delays, and that by purchasing machines as nearly standard as possible, and by modifying the contract to a reasonable extent, to suit

the manufacturer in unimportant details, much better terms could be made without increased trouble to either the purchaser or the engineer.

The contract forms submitted by many manufacturing companies are unfair to the purchaser, in that they are wholly one-sided, and are intended to protect the seller in every way possible, while the rights of the purchaser are given but little consideration. Such contract forms are far too common, and for the credit of the profession it is hoped that these may be modified, and brought to a more equitable basis.

The ordinary proposals submitted by many companies are equally unfair. Perhaps the most flagrant instance of this is the statement in many bids that they are not effective until approved by an executive officer. Such proposals are not worth the paper they are written on, and should not be considered for a moment by any self-respecting engineer, as they in no way bind the bidders, and their acceptance simply ties up the purchaser. Instances are not lacking where manufacturers have taken advantage of this clause to repudiate bids apparently made in good faith. So common is this practice that it has become necessary to incorporate a clause in the "Notice to Bidders" to the effect that proposals which are not made in good faith will not be considered.

Another unfortunate practice is that which many manufacturers have of asking the return of their proposals and accompanying data as soon as the award is made. These papers are necessary to the purchaser and the engineer, to make a complete record of the transaction, and should be retained by them.

On the other hand, it must be admitted that some engineers' specifications are unfair to the manufacturer. The points on which these complaints are based have been given due consideration, and in my own practice have led to the following rules:

First.—When it is desired to permit the bidder some elasticity, and not to require him to adhere rigidly to the specifications, the "Notice to Bidders" contains a clause reserving the right to waive informalities.

Second.—The engineer is made the arbitrator of all disputes, but appeal is always permitted to a referee or referees. If the contractor thinks he is being treated unfairly he may avail himself of this privilege.

Third.—A clause is frequently inserted to the effect that

where a special make or type of apparatus is mentioned in the specifications, it is not intended to mean the exclusion of all others, but simply as establishing a standard of excellence. The bidder may substitute other apparatus in his proposal, the engineer reserving the right to judge as to whether the article offered is equivalent to that specified.

Fourth.—Where the work is such that it is impossible to go into details very fully, and where the apparatus is of such a character that different builders offer different types of construction, which accomplish substantially the same results; or where it is desired to secure the benefit of the most recent improvements, a general clause like the following is sometimes inserted:

"While it is believed that the following specifications properly cover the needs of the purchaser at this time, they are not necessarily final. Bidders are invited to submit alternative propositions embodying any other types of apparatus, or other details of construction, which in their judgment may seem as well, or better, adapted to the purchaser's needs."

It is to be hoped that this presentation of the matter may result in a better understanding among all parties interested, as to mutual obligations and responsibilities. I believe I may say for the engineers that they will meet the manufacturers fully half way in an effort to reach a more satisfactory basis of coöperation, and to bring about a higher standard of design, workmanship, and efficiency, and a more uniform and equitable definition of contract relations.

DISCUSSION.

Col. E. D. Meier.—From the standpoint of the manufacturer and contractor I must say that I heartily agree with most of what Mr. Bryan has said. It is an unfortunate fact, as most engineers have noticed, that in the mind of the average client with whom we have to deal the architect is a superior being, and the engineer is to be employed occasionally, but not to be given much weight after all; and it is partly due to the fact which Mr. Bryan has mentioned that the purchaser does not come into such close and intimate relations with the engineer as with the architect. Every man naturally draws his illustrations from his own practice, and therefore I may be excused if I refer to the boiler in this connection. We have often had specifications for boilers

where, for the convenience of the architect, the boilers were to be made part of the heating contract. While there are a number of first-class steam-heating contractors in the United States, our experience has been that only once in ten times does one of those large responsible concerns get the contract. The contract is generally given to some plausible fellow who happens to have a little credit with the man who sells the pipe, and he then has the say in everything. He even draws the specifications for the architect, which ought to be drawn by a competent mechanical engineer, and the consequence is that the boiler firm, which perhaps is the more responsible of the two, has to look to this heating firm for everything, and they are therefore placed at a disadvantage. First of all, the specifications are generally so drawn as to favor some one who has favored this little steam-heating contractor. Then, instead of the pay coming direct from the owner of the building, as it should, it sifts in some way through the steam-heating contractor, and sometimes it takes several years to sift through. Now, that would be avoided if, instead of taking some irresponsible party as an assistant to the architect, a party so irresponsible that his name does not even appear; if, in the case of a large office building, for instance (one such case is enough, and it will illustrate as well as any other), where the mechanical details are fully as important as the architectural details, the mechanical engineer should stand on the same level with the architect, and matters relating to boilers, engines, dynamos, steam piping, shafting, etc., should be distinctly and directly left to the mechanical engineer, so that we should know with whom we are dealing. Every honest manufacturer or contractor can do better work under those circumstances than when he has to deal with irresponsible parties. That is one thing.

Another thing is the frequent mixing up of things which are entirely separate, and compelling the one to depend on the other, simply on account of the laziness of the architect or of the mechanical engineer who may have been employed. I have one case in mind which is characteristic, and has occurred a number of times in the last few years. It is that responsible boiler firms were compelled to bid, giving certain guarantees on performance with certain classes of furnaces, the boiler firms in every instance having more responsibility than the furnace firms, the boiler men being compelled by the consulting engineer to guarantee results with those furnaces, so that they stood the chance of loss and the

furnace man could go out scot free. His word was simply taken that he could do so and so, and he could do it with such and such boilers. Why should not he be made to prove his own guarantee? Now, there is a case for a rational mechanical engineer to step in—a man who is not lazy and has the courage of his profession—and say: "It is MY responsibility as a mechanical engineer to separate those two things. I can tell whether it is the furnace or the boiler that is at fault, and I will hold the *proper* party responsible."

Those are just two instances that I refer to, but there are a great many others, such as specifying a certain material by name or by brand when the manufacturer knows that he is in the habit of using better material, and for the sake of the protection of his own prestige and standing wants to use a better material, but cannot do it because a poorer material is specified by a certain brand. There is another chance for a mechanical engineer, and I think that this Society could do nothing more calculated to improve the standing of the mechanical engineers than to adopt Mr. Bryan's suggestion of drawing up a set of general specifications which will be binding on the mechanical engineer as well as on the manufacturer and contractor. That could be done by getting representatives—there are in our body here representatives of the manufacturers or contractors and representatives of the consulting engineers as such; and if the Council will appoint a committee to formulate some of these points, then the grievances both of the contractors and the mechanical engineers could be laid before such a committee, and I think general specifications could be drawn up under which both could work harmoniously, and it would be a blessed thing for all the manufacturers when we could appeal in such cases to mechanical engineers having a proper understanding of the ethics of the profession.

Mr. Chas. W. Barnaby.—I desire to enter my protest against the practice of compelling one manufacturer to guarantee another's product, which has been referred to by the last speaker. In the engine business we strike this in connection with steam pumps and condensers used with the engines. I recall one case in particular where those who bid under the specification were compelled to make a guarantee on steam consumption of two small engines, the steam consumed by the feed pump to be charged to the engines. The steam pump was only to supply the feed to the boiler during the test, but was much larger than necessary for that purpose, and consequently consumed more steam than would

be required by a pump of the proper size for feeding the boiler. The pump and engines were in separate divisions of the specifications, and were expected to be furnished by separate contractors, and if my recollection serves me, when the engine proposals were called for the pump contract had already been closed, so that the pump was entirely out of the engine bidders' control.

It is not right for the architect or engineer to draw up specifications in such a manner as to compel one manufacturer to guarantee another manufacturer's product. If they desire a guarantee on engine, condenser, feed pump, and boiler they should have each manufacturer guarantee his own product, particularly when they are furnished under separate divisions of the contract. There may be a little excuse for compelling one manufacturer to guarantee the other's product when the specifications are drawn up in such manner that one contractor must furnish all of the machinery of whose performance he is required to guarantee the economy. Then he is in a position to demand a guarantee from the manufacturer from whom he purchases those parts of the outfit which he does not manufacture himself, but the very common practice of compelling the contractor in one division to guarantee the economy and performance not only of his own machinery, but also that furnished by another contractor under a separate division of the specifications and over which he has no control whatever, is entirely wrong and uncalled for. It seems to me that this is an injustice that those who draw up specifications should recognize, and which might be corrected by having a standard specification formulated by a committee.

Mr. T. W. Hugo.—There are several points of view from which we may observe the relation which the consulting mechanical engineer bears to the purchaser and the manufacturer. If he is merely the mechanical expert, his ideas will be drawn off in the direction suggested by Mr. Barnaby and Mr. Meier—that is, he will look upon that side of the question entirely; but if he is in the capacity of the confidential adviser of the purchaser to stand between him and the manufacturer, to put into plain words the technical language of the seller, and weigh the statements made and accord them their fair value, he is then in another position, and I think we should consider him as a two-sided individual, in the one case the mechanical engineer and adviser, and in the other the confidential friend and adviser engaged by the purchaser to protect himself from imposition.

I have generally found that the purchaser turns out to be the under dog, the manufacturer being more experienced and able to take care of himself, and I believe the consulting mechanical engineer will come more into favor when he is able to be as good a business man as he is a mechanical engineer, and thus be the better fitted to serve his client in those things which, as a mere engineer, he is apt to throw on to his employer. I also think that our interests as consulting mechanical engineers are with the purchaser, securing for him that for which he pays his money, after seeing that the specifications are properly prepared and the contract securely drawn, and then in case of dispute acting as judge, and doing equal justice to all parties concerned according to the documents so prepared.

I think a standard set of specifications, except as to a few general clauses, would be of little use, for the reason that different conditions prevail in different parts of the country, different business methods and usages, and different mechanism and apparatus used, so that the specifications would have to be so broad as to be practically useless, and subject to great modification in each case. Besides, under such a standard we are liable to get into a rut, which should be avoided.

Colonel Meier.—I would just mention one other little incident which I have come across in practice several times, and that is a form of architect's specifications in which, after going into a long typewritten specification of just what is wanted, there is this little printed clause at the end—I cannot remember the exact wording, but the meaning of it is this: "If I, the architect, have forgotten anything, you, the manufacturer, have got to supply it."

*Mr. Bryan.**—I believe there is little further to be said at this time. I want to call attention, however, to a point mentioned in the paper, that in England the manufacturers and engineers have already gotten together and adopted standard forms for the "General Provisions" which are always introductory to the specifications covering the details of the work. The American Institute of Electrical Engineers has also appointed a committee, with a view, if possible, of agreeing upon some standard form of specifications or standard method of making tests of electrical machinery. The point has been made of the objections to combined contracts, particularly where they embody guarantees of different

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* Author's closure, under the Rules.

parts of the work. This is one of the greatest difficulties we meet with, and can only be solved in each case by considering the special circumstances surrounding it. We all know how much better it is to have all the work of a certain character, or field, in the hands of one contractor. In spite of all that we can do, it is almost impossible to clearly define the point where one man's responsibility ceases and the next man's begins, and that, of course, is why we combine contracts as far as possible. Now it seems to me that when that is properly done it is not such a bugaboo after all. It is, of course, unfair, as has been so frequently said, to hold the man taking the contract responsible absolutely for the guarantees of each of the different sections; but if in the paragraph defining the method of making the guarantee tests and stating the conditions of acceptance it is clearly explained that the failure of any particular section of the work will not invalidate the whole contract, or hold back the contractor's money on other sections, and that he can go ahead with the rest and get a settlement and acceptance, it seems to me that we have removed the most serious difficulty. The general contractor in such cases should always protect himself by the same character of contract and bond from the sub-contractors that he has himself given the principal.

As to the relations of the engineer to the contractor and to the purchaser, I have always assumed that up to the time of drawing a contract the interests of the engineer are almost wholly with the purchaser, but after the contract is once drawn and is in effect, the engineer occupies more nearly the position of an arbitrator. While he is paid entirely by the purchaser, he still has certain obligations to the contractor. The contractor has a right to look to him for a fair and reasonable interpretation, not a one-sided interpretation, of the specifications, and from that point of view the contractor, it seems to me, has a protection which he would not get ordinarily directly with the purchaser.

DCCLXXX.*

NOTE ON THE CARBON-CONTENTS OF PISTON-RODS AS AFFECTING THEIR ENDURANCE UNDER FATIGUE.

BY JOSEPH E. JOHNSON, JR., LONGDALE, VA.
(Junior Member of the Society.)

THE subject of the relative endurance under reversed stresses of materials of different tensile strength and hardness, has recently been attracting a considerable amount of attention from engineers, and the theory, until recently universally held, that for withstanding these repeated or reversed stresses a very soft material was necessary, has had to be revised to the extent of complete abandonment, at least in many cases. It is not with the idea of communicating anything new, but merely as a strictly practical confirmation of the valuable work done by others that the following data are given.

About six years ago the company with which the writer is connected bought a compound locomotive of the Baldwin or Vauclain type, no description of which is needed before this Society, except to recall, for the sake of clearness, the fact that the high and low pressure cylinders lie as close together as possible, one vertically above the other, the rods from the two cylinders being fastened to the same crosshead, which is of the four-bar type, and located centrally between the two rods, as shown by the accompanying drawing (Fig. 170). The wings or guiding surfaces are made very long in the direction of the stroke, to overcome the torque set up by the unequal and constantly varying pressures on the high and low pressure pistons respectively. These pressures are made as nearly equal as possible by the steam distribution, but practically there is always considerable difference at some part of the stroke, so that there is a stress tending to tilt the crosshead one way during one stroke and the opposite way during the other. This stress puts a considerable pressure on the diagonally opposite corners of the guiding wings, and,

* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

the reciprocating motion going on while under this pressure, wear takes place on the corner of the wings first, and allows a slight rocking of the crosshead, a complete oscillation occurring at each revolution when running under steam.

The piston-rods are fastened to the crosshead with the regular taper fit drawn up to a shoulder by a nut. This connection being rigid, and the opposite end of the rods prevented from vibrating with the crosshead by the fit of the pistons in the cylinder, the rods are bent at the shoulder through a very small arc in each direction vertically, at each revolution.

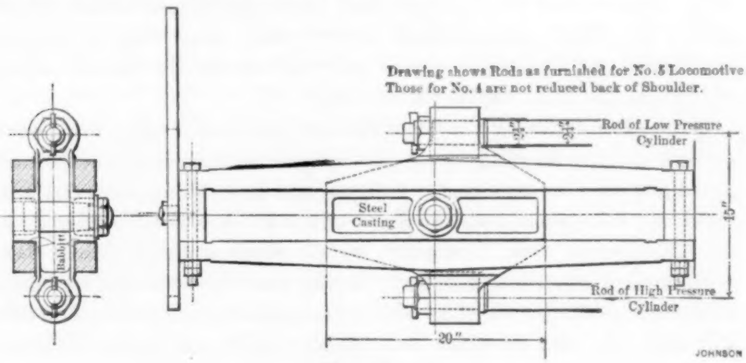

FIG. 170.

This first locomotive ran for three years and two months, when a duplicate was bought, and the first put in the shop for a general overhauling previous to taking the place of the smaller engines on another part of the road, the new one taking the run of the old one. During the overhauling the piston-rods were renewed, having worn down too small to work well with the metallic packing any longer. The material for the new rods was ordinary "machinery steel," taken from stock on hand. The rods on this engine (No. 4), it should be stated, were straight from shoulder to shoulder, while those of the "duplicate" (No. 5) were reduced in the body, having a collar $\frac{1}{4}$ inch larger than the rod and $\frac{1}{2}$ inch wide next to the shoulder at the crosshead end.

After having been in service about fourteen months, one of the low-pressure rods of No. 5 "let go," and smashed the cylinder-head, without, however, doing any very serious damage. Within a few weeks the overhauled engine did the same thing.

This was becoming a serious matter, and after some careful consideration the writer ordered some genuine Swedish iron

to make rods of. It was beautiful stock, and so soft that it acted almost like lead in the lathe, being very difficult to get a smooth finish on. A set of these was put into one of the engines at once, and ran about *four months*, when one of them let go in the same way. The rods that broke were all low-pressure ones, due undoubtedly to the fact that in the "emergency," or starting gear, those cylinders get almost full boiler pressure; 180 pounds per square inch. The rods were all broken in the same way, and right in the shoulder, the metal cracked at top and bottom, and the crack gradually widened, as could be seen by the worn appearance of the upper and lower segments of the break, which gradually approached each other until only a narrow horizontal strip of solid metal was left across the middle of the rod when the final rupture occurred.

Soon after ordering the Swedish iron, the writer came across one or two articles bearing upon this subject of the endurance of soft and hard steel or iron under fatigue, and describing tests made to elucidate this point, notably those of the Pope Tube Company and the Bethlehem Iron Company, which showed quite clearly that high-carbon steel was infinitely better than low-carbon, and that nickel-steel was better than either for such service; also that very soft material, like Swedish iron, lacked endurance under fatigue.

Therefore the breaking of the rod of this material was not a very great surprise, and was met by ordering material for a set of rods of high carbon and one of nickel-steel from the Bethlehem Iron Company. These have now been in considerably over a year, and we hope that they will last long enough to wear out without breaking.

The writer had the three rods which had broken, and the one which had worn out, analyzed, to see how they bore out the theory of high-carbon material *versus* low.

The results are given herewith:

	Sulphur.	Manganese.	Phosphorus.	Silicon.	Carbon.
First rod in No. 4 locomotive; machine steel; ran three years and two months without breaking....	.094	.70	.082	.014	.466
Second rod in No. 4 locomotive; machine steel from Longdale stock; ran fifteen months and broke.....	.056	.64	.125	.021	.152
First rod in No. 5 locomotive; iron; ran fourteen months and broke...	.020	.12	.04	.148	.129
Third rod in No. 4 locomotive; Norway iron; ran four months and broke	.006	.05	.055	.021	.044

It will be seen that these results bear out the theory to a striking extent, there being nothing in No. 1 to cause its far greater endurance except the carbon, and possibly to a slight extent the sulphur, which is also claimed by some to be a hardener.

It is very difficult to deduce any quantitative results as to number of reversals of stress producing flexure even approximately, because even given the approximate daily mileage of the engines and the size of the drivers, it is impossible to say what portion of the total running was done under steam, the grades being quite heavy, and the trains running by gravity for nearly half the total distance.

If thirty miles per day under steam, twenty-eight days per month, be taken, the diameters of the drivers being thirty-six inches, the revolutions per day would be, say 16,000, and per month say 450,000; this would make for the second and third rods about 6,000,000 double flexures before rupture, and for the Swedish iron rod say 1,800,000.

There is no way of giving the amount of flexure; the crosshead probably never tilted more that $\frac{3}{64}$ inch in twenty-four inches to either side of the vertical, but this amount varied as the wear occurred, and was taken up; also it is not possible to tell what portion of the total length of the rod absorbed this flexure, so that it is impossible to give any figures having a scientific value.

The theory of the superior endurance of harder materials under fatigue has been explained many times, and by those far more competent to do it than the writer, so that nothing on that subject is said here.

As stated at the beginning, this is only intended as a strictly practical confirmation of facts already brought out by the splendid researches of others.

DISCUSSION.

Mr. Thomas R. Almond.—Hardened steel, if immersed in a liquid such as a solution of cyanide of potassium, may become weakened, and if it remains there long enough it may break. A fracture may be started as soon as immersion takes place, or something similar to a fracture. There is a condition which I do not understand. The liquid seems to get in between the molecules at some portions of the surface, and weakens the material. The first time that I observed this was when cleaning some steel springs which were under tension. I left them in a weak solu-

tion of cyanide of potassium over night, and to my surprise in the morning they were broken. It set me thinking, and one of the conclusions to which I came was that, where rods are continually under stress, possibly the molecules may become sufficiently separated at the most distressing time of the motion of the rod, and any acid which may be present in the oil or lubricant which is used may possibly have an influence upon the material towards weakening it. I have often thought that the breakages which occur in the crank-pins of locomotives, at the weakest portion—that is, the corner which comes nearest to the wheels—are probably due to acid in the lubricant being absorbed when the stress is greatest. It is easy to understand that the molecular density will be less at that moment, and that there may then occur an absorption which perhaps might not occur before. This continued through a long period of time, and under the same circumstances every time, may very materially assist towards bringing about fractures which are often considered as being very mysterious, more especially when the material used is known to be of high quality.

Mr. H. H. Suplee.—I think in considering the breakages which are described in the paper, sufficient emphasis is not given to the peculiar conditions under which the piston-rods in these Vauclain compound engines work. I have had occasion to observe a number of these engines running in and out of Philadelphia, and there is certainly a very severe and very sudden stress on those rods. In the first place, there is nearly always a considerable amount of clearance between the guides, and if they are not so made they soon become so. This permits a tilting of the crosshead which is very marked on starting; and, furthermore, it takes place in a very short space of time, and is very much more in the nature of a blow on the rods than of a bend. When the steam is admitted you can hear the crosshead tilt with a clank like the blow of a hammer, and then there will be a corresponding sharp blow on the return.

The bending is not distributed over the whole length of the rod. It occurs in the first few inches of the forward stroke and the same on the back portion of the stroke. It occurs until the engine is well under way, when the pressure in the two cylinders is equalized and the sound disappears. Then I think it is supposed that the pressure in the two cylinders is so nearly equalized that the bending is comparatively slight. The result is that these rods at starting, for a few strokes, are practically being hit a sharp blow at the end of the stroke, and then, after that, these

hammer blows cease, and it runs quietly enough until it slows down, and on the next start the same thing is repeated. I think three are not so many bends as stated in the paper, because this action takes place only on starting. It is not like an ordinary test, but more like the hammer test or drop test than mere bending, and that, I think, would have something to do with the manner of these breakages.

Mr. Gus. C. Henning.—I fully concur in what Mr. Suplee says. Clearance is given, and because of this they have been compelled to make their crossheads so much longer, so as to avoid this very shock. It is intentionally left there, because of this very action the crossheads would bend at the beginning of the stroke. They must give some play between the guides. But I claim the gentleman has not proved his case, anyway. He does not tell you how much strain is produced when the full steam pressure of live steam is put on the low-pressure piston-rod, for which, of course, it was not designed originally. It was designed for a lower pressure and not for the higher pressures. But practice has compelled them to make them heavier. Whether they are proportioned to the load that comes on now, is the question. The table of chemical analysis does not prove what he says it does. Let us throw out of consideration the phosphorus and silicon, because of the varied effects on the material of the two elements under various conditions, and consider merely manganese and sulphur. Sulphur we know is a strengthener, a hardener. As the carbon is higher in this case, so is the sulphur. Therefore we can say that a part of the greater strength of the rods is due to sulphur. Manganese is a softener. Piston-rods are rolled and allowed to cool gradually and turned up. In that case these rods which have the highest manganese should be the most ductile and give greater life. Look at that table again, and manganese is higher as the carbon is higher. I know it is generally true that the higher carbon steels were longer. I should not deny that at all. I simply say that this table shows that these rods might have a longer life, either because the carbon was higher or the sulphur or manganese was higher. Now we have two against the carbon —the sulphur and the manganese, all in the same direction. Therefore I say that this table does not show anything except that those rods may have worn longer for any other reason except that due to the higher carbon contained in the steel.

Mr. Jno. E. Sweet.—I think the story cannot be too often told

that there are certain cases where the high steel does better than the soft steel. There is another way to get over the same difficulty mechanically. Every one who makes a good hammer handle whittles it down small between where the hand takes hold of the handle and the hammer. He does not do it to save wood, but he does it to add to the life of the handle. A bright genius some thirty years ago discovered that where axles were breaking near the wheel he could increase the life of the axle and also save metal if he brought it down in the centre. My brother, as I have before stated to this Society, discovered that piston-rods were breaking where they entered the hammer heads of his steam hammers. He scooped out that part of the piston-rod between where the packing came and the hammer head, and increased the life of the piston-rod 300 per cent. I would suggest the same in this case. If you scoop it out for as long a distance as can be spared, you have always got the depth of the gland; you will add to the life of the rod. Or, to put it in a form that you will remember, you will make it stronger by making it weaker. Whether a round groove is the best way, or whether it is better to reduce it straight with a round nose tool, mathematicians can tell you better than I can. Manufacturers cannot do either. If they did they could not sell the engines. But the man who buys them can take his rods and turn them down, and he will increase their life immensely.

Mr. Almond.—Professor, won't you state why that is?

Mr. Sweet.—You diffuse the strain.

Mr. Almond.—You lessen the rigidity?

Mr. Sweet.—Yes, make it limber for a longer distance.

Mr. Henry Souther.—I had an opportunity to visit Normand's Torpedo Works in Havre last year, and found that he was necking, somewhat in shape of a blade, all of his connecting rods with this same idea in view, and also with the idea that should the bearing not be perfect when the engine was new, that the rods could yield to any slight inequality. The success which he was meeting with induced him to continue the practice. This paper is particularly interesting to me, because I have been working over alternating stress, and rely upon this test as a final judgment on material, and there is certainly no question but that the carbon element is of greater influence than any other element that we have been able to get hold of, possibly excepting nickel.

Referring to the paper on cracking of boiler-sheets—boilers are

rather out of my element—it seems to me too bad that some other material than iron cannot be resorted to. I do not know that it is possible, but it seems that if higher carbon steel could be gotten into boiler stays that some of the stay-bolt breakage would be lessened.

Mr. Spencer Otis.—Referring to what Mr. Sweet has said, I have seen practically what he recommends for increasing the life of a piston-rod. The end has simply a taper fit, and the ordinary keys put in for a fillet when the rod enters the socket, with a nut on one side, and a radius is made as long as possible. On an average I have seen a change to the shape shown more than double the life of the same piston-rod without any change of material.

Prof. S. W. Robinson.—I think many of the Society may recall what was once written about a steam hammer. In overcoming the trouble of breakage of the piston-rod, it was made a great deal smaller in the whole length, and consequently weaker in theory, but it stood several times as long in practice. It strikes me that this is a good point for consideration, that the rods may even be made smaller than they are. By overdoing the thing, enlarging by putting in metal, we weaken it *practically*. I was told of a case that came in the experience of an expert who was called in to examine a machine which had one part continually breaking. They had strengthened it up repeatedly, and the more they strengthened it the more it broke, until they called in the expert, Mr. J. C. Hoadley, who, on examining the machine, said: "You have done just the wrong thing. You have made it so big and stiff that it cannot vibrate, or cannot accommodate itself to the tendency to vibratory motion of the parts, and consequently the parts get such severe strains that crystallization and breakage occur. You put in a rod about one-fourth the size of the first one." With that rod in place, no further trouble came to the user of the machine.

Mr. Sweet.—We cannot reduce the engine piston-rod down to anything small enough just to stand the tensile strain, but must have it large enough to stand compression without buckling, whereas, if it is to lift a steam hammer, there is only tensile strain on the rod, and it can be made as small as tensile strength will permit.

*Joseph E. Johnson, Jr.**—The remarks of Mr. Almond, espe-

*Author's closure, under the Rules.

cially with reference to the fracture of springs in a cyanide solution, are very interesting; but the suggestion that the molecular density of bearings such as crank-pins may be so reduced under strain as to facilitate the absorption of acid from the lubricant and so be injured, while very ingenious, seems to the writer impossible.

When the smallness of the distortion produced in any proper bearing by the working stress is considered, it would seem that the volumetric dilution of any portion of the solid must be an infinitesimal of high degree, and the increased opportunity for the action of acids or other substances must be very slight indeed.

This is less the case with the springs, in which the distortion of the metal is really considerable.

As far as the fractures of locomotive crank-pins are concerned, they should never, we would think, be classed as mysterious; the really mysterious thing is that they stand as well as they do under the terrific duty they are called upon to bear.

As far as the fractures of the piston-rods described in the paper are concerned, allowing full value to the theory of Mr. Almond, it would not appear that it was of great importance, because of the freedom from the presence of oil at the point of fractures and the entire sufficiency of the conditions to account for the breakage without the aid of this theory.

Mr. Suplee avers that sufficient emphasis is not laid upon that point of the paper which was intended to be the kernel of the whole matter, the tilting of the crossheads, and consequent flexure of the piston-rods, though in making good the omission he has used language not differing greatly from that of the paper.

He has, however, made one or two statements which need correcting from the point of view of the facts.

The guides are not given a considerable amount of clearance at the start, but are lined up as closely as those of the ordinary type of engines, but they do get some freedom of motion through wear at the corners after a short time.

There is no apparent reason, from the point of view of theory, why the bending strain should be absorbed in the first few inches of the rod; on the contrary, there is nothing to arrest the tendency of the crosshead to rotate, except the pistons pressing against the walls of the cylinders until the lost motion is all taken up, and the guides prevent further rotation. The stuffing box, in the present instance at least, may be neglected, since the packing is metallic,

and provides for far greater lateral motion of the rod than the flexure ever amounts to.

This being so, the piston-rods held at the end by the pistons simply act like cantilevers levelled at the end, and must be bent throughout their length.

The proof of this is that the cylinders are worn in a very unusual way which can be accounted for only by this action of the pistons in trying to resist the rotation of the crosshead.

The flexure is undoubtedly greatest at the crosshead end, especially as the section at which fracture occurs is smaller than the body of the rod, but all flexure not absorbed here must be distributed throughout the length of the rod as in any other cantilever.

The same speaker also says that this action only takes place when the engine is starting, and that thereafter the pressures on the two pistons are so nearly equalized that the bending effect is comparatively slight, but in this he is in error, as a matter of both fact and theory, for actually, as observed from the engine itself, the tilting which causes the bending goes on all the time.

It is perfectly true that the inequality of pressure on the two pistons is greatest when starting, and live steam is turned into the low-pressure cylinder, but if Mr. Suplee will take a complete set of indicator cards from both cylinders of one of these engines, or lay out a set to suit the given conditions, he will find that it is impossible to have more than one load (and in practice not that) at which the pressure is even approximately alike in both cylinders throughout the stroke.

The *work* may be approximately equal in both for quite a wide range, but the pressure on one piston will be greater at one end of the stroke than on the other, and less at the opposite end, practically in every case.

It is to be remembered that only a trifling difference of pressure on the two pistons is necessary to tilt the crosshead, until the lost motion is taken up, and therefore that it is safe to say that the crosshead is tilted every stroke when the engine is running under steam.

For corroboration of this statement, those who are interested are advised to examine the indicator cards published by the Baldwin Locomotive Works themselves, a few years ago, in a pamphlet descriptive of these engines. Mr. Suplee also states

that the stress which comes on these rods is more like a hammer test or drop test than an ordinary bend, and here again I am compelled to differ with him. The stresses alternate in direction very rapidly, it is true, but so do those in a rod revolving between lathe centres at a high speed and carrying a heavy weight at the centre, yet that is not a hammer blow or analogous to it. The criterion of a hammer blow or drop test is that the test piece shall absorb the energy of the drop, but in this case the energy of the crosshead and the work of resisting the suddenly applied bending movement are taken by the guides and the crosshead wings, the work done in bending the piston-rods is insignificant as compared with that expended on the above parts, and therefore while a suddenly applied and reversed stress, this is not in the nature of a blow. Mr. Henning's remarks in part resemble those of Mr. Suplee, and need not be dealt with separately in those parts, except to say that whether or not clearance is allowed between the crosshead and guides does not affect the bending moment at all, but only the extent to which the rods can be flexed, and therefore, as before stated, the crossheads are, in practice, lined up as closely as possible consistent with good working, and it would be highly desirable if they would stay so, so much so that in our case we have substituted cast-iron gibs for the babbitt facing on the crossheads, because, under the heavy pressure at the corners, the babbitt flows and is forced out, while the cast iron does not.

The same speaker says that the stress produced by live steam in the low-pressure cylinders is not given, and evidently thinks that that may account for the fracture, although the fracture itself precludes such a possibility by its appearance.

Moreover, all the data are given to make this calculation, and are as follows: diameter of cylinder, 17 inches; diameter of rod at shoulder, 2 inches; pressure of steam, 180 pounds.

From this it is seen that the tensile stress due this course is about 13,000 pounds per square inch, which is entirely insufficient to cause such breakages. The same speaker says the rods were not originally designed to stand this pressure, and had to be made heavier to do so, but he fails to give his authority for this statement, which seems improbable; and, moreover, the makers made the rods in the second of these engines $\frac{1}{4}$ inch smaller in the body than the first, although the shoulder and taper are the same in both.

As regards the part of his remarks bearing on the chemistry of the subject, Mr. Henning says that sulphur is a strengthener and hardener,which is probably correct as far as it goes, although no one has yet come to the point of demanding high-sulphur material for these properties; but leaving for the moment this point, he further says that manganese is a softener; that the high manganese contents of the No. 1 rod would make it more ductile, and therefore give it greater life. He then proceeds to say that manganese and sulphur act in the same direction, and that the effect of both is similar to that of carbon. But if one be a softener and the other a hardener, how can the effect of both be the same?

It is quite in order here to point out the comparatively small variations in sulphur and manganese, and the large one in the carbon, also the lack of any obvious connection between the action of the rods and their sulphur and manganese contents, as compared with the presence of such connection in the case of carbon.

Moreover, the fact that a speaker should think that an element which would make a material more ductile would also make it better able to withstand unusual stresses, shows how much need there still is for missionary work along this line, since it was the expressed purpose of the paper to supply confirmatory evidence to the opposite of that proposition.

Whether the evidence is valid on this point, each one must decide for himself.

The proposition of Professor Sweet is undoubtedly in the right direction, and that was probably the idea the makers had in mind in reducing the body of the rod forward of the shoulder.

It is hardly possible, however, to make the rod smaller than the large end of the taper, as it properly should be, because the tensile stress would be too high for safety, but if the shoulder, collar, and taper were all increasd in size so that the large end of the taper, where the fractures have all occurred, were made larger so that the latter part were, say, a quarter of an inch larger than the body of the rod, then the trouble would probably disappear entirely, especially if a material of a moderately high carbon-contents were used.

The collar would not involve any additional complication in the packing and glands, since these all have, with the present shoulders on the second engine, to be made in halves, held together by

threaded rings long enough to go over the collar. The crossheads in the present case, however, have not enough material in them to permit of this enlargement of the socket with safety.

This construction would also avoid the obstacle mentioned by Professor Sweet in the case of the reduced rods, that no one would buy an engine which had them.

DCCLXXXI.*

PLEA FOR A STANDARD METHOD OF CONDUCTING ENGINE TESTS.

BY GEORGE H. BARRUS, BOSTON, MASS.

(Member of the Society.)

THE action of the Society in the past in devising standard methods of tests in various lines of engineering is well known to the members, and it is believed that the work thus far done has been creditable to the organization, and has given the Society a position in the engineering world which it would not have occupied if it had followed a different policy. In the steam engineering line we now have a standard of boiler testing (Atlantic City meeting, 1885), a standard method of conducting duty trials of pumping engines (Richmond meeting, November, 1890), and standard methods of testing locomotives (Chicago meeting, August, 1893); but we have thus far no standard which applies to the general subject of engine testing. Having done so much in making uniform the various methods of tests in steam engineering, it is evident that further standardizing should be undertaken, so that the whole subject may be covered. It seems to me that the time has come when the Society should take up this matter and appoint a committee for devising a standard method of making engine tests in general. Its work in this line will then be no longer incomplete.

The present need of a standard method of testing engines is perhaps less urgent than that of testing boilers, pumping engines, and locomotives, which have received attention at the hands of the Society; but the same general reasons may be advanced in its favor as those which may be found in the reports of the various committees; that is, to bring the methods of testing employed by different experimenters into harmony with each other, and to inaugurate a standard method of reporting the results of engine tests and of expressing engine efficiency.

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* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

The determination of a standard method of testing engines in general would naturally precede the determination of methods of testing individual types of engines; or, if it did not precede such work (as, in the case under consideration, it cannot), it should be so far in harmony with the individual methods that there might be no interference. So far as the working of steam in the cylinder is concerned, one type of engine is very much like another, whether its force is expended in turning a shaft for generating power to drive a mill or other mechanism, or to pump water, or haul a train of cars; and the operations of determining the efficiency with which the steam performs its work are much the same in one as in another. Looking at the subject from this single point of view, it is a late day to be advocating a standard method of general engine testing, for it should preferably have been taken up prior to the work done by the committees on duty trials and locomotive testing. Nevertheless, the work is something which I have long thought should be undertaken; and if, owing to the exigencies of the times, the best order has not been followed, it is not too late to correct the error, if such it be.

I am inclined to the belief that it would be well now for the Society to not only prepare a standard of general engine testing, as suggested, but, at the same time, to revise the work of the two committees on duty trials and locomotive tests, in so far as should be done to bring all three into harmony; and then combine the whole subject of engine testing, whether it be on one type of engine or another, into a single report. There is so much in common amongst steam engines used for different classes of work, that there ought to be little difficulty in devising a standard of testing and reporting efficiency which would be applicable to all, whether employed in pumping water, hauling trains, operating electric generators, propelling ships, or driving any other kind of mechanism; and, furthermore, there ought to be no difficulty in modifying such a standard so as to make it applicable to the peculiar conditions of service required in any individual case. If a revision of the work of the two committees referred to should be undertaken, I would not advise changes in the substance of their recommendations; for these, so far as I know, are acceptable to the Society. What I do suggest is that the whole matter of engine testing be brought into one uniform system, with suitable modifications adapting it to individual requirements; and publish the report or code, whatever it may be called, in one com-

prehensive document. If this were done, the Society would have simply two standard systems of making steam-power tests: one relating to boilers, which, at the date of writing, is about to be submitted in the form revised by the committee of 1895 for the consideration of the Society, and the other relating to engines. The subject of steam-plant tests would then be in such shape as to be most convenient for the use of members and others interested, and it would be of increased value to colleges, which, as I understand, regard the Society's reports as valuable standards of reference in the instruction of students.

SUGGESTIONS AS TO A STANDARD SYSTEM OF TESTING ENGINES.

The principal data required for an efficiency test of a steam-engine are the weight of steam consumed and the amount of power developed. These two elements of data are fundamental whatever the type of engine and whatever the class of work performed. It is evident at the outset that a system of engine testing applicable to all engines would be a method of determining these quantities. Consequently the proposed standard would relate primarily to these two things and to the expressions of efficiency derived therefrom.

If, for the moment, we pass by the steps required to obtain the necessary data, and take up the problem of bringing into uniformity the methods of reporting the results obtained from different classes of engines, the subject arranges itself in a simple manner. The desired uniformity will be secured if the tabular summary of results is expressed in two sections: the first section dealing with such data as apply to the working of the steam in the cylinders, apart from the peculiarities of the service which the engine performs, and the second section giving the data and results pertaining to the special individual work. Following out this scheme more in detail, the first section of the tabular report would contain all the data of measurements of feed water, of steam used by the jackets and reheaters if these were employed, the quality of the steam, the weight of steam used by the auxiliary apparatus, and all the data of the various pressures, temperatures, and speed relating to the work of the engine, including the pressures and other data obtained from the indicator cards. It would give the horse-powers developed, the weight of steam consumed by the engine and by the auxiliaries in a unit of time per unit of power, the deductions from an analysis of the

indicator diagrams, and the total number of heat units consumed in a unit of time per unit of power. It would also present the standard decided upon for the expression of efficiency.

The second section of the tabular report would vary with each class of engine. In this section there might be five subdivisions, one applying to each main class of engines.

The classes which suggest themselves to me are as follows:

1. Factory engines, or engines employed in the production of power in general.
2. Pumping engines.
3. Locomotives, (*a*) shop tests, (*b*) road tests.
4. Engines employed in generating electricity.
5. Marine engines.

In the first subdivision of the second section, that relating to engines for general work, few additional data need be given beyond those found in the first section. Engines in general are employed in generating power for such a variety of mechanical operations that the simple expression of efficiency, based on the quantity of heat or steam used per gross or net horse-power per unit of time, covers essentially the whole ground. This section might, however, present the data and results of a coal test of the engine where this was made, in which case it would give the weight of coal burned and all the various results depending upon it.

The second subdivision of the second section, that relating to pumping engines, would present the special data in regard to the work of the water end of the engine, such as the quantity of water pumped, the number of feet lifted, and all the special data which are given in the report of the duty trial committee in vol. xii. of the *Transactions*. In this section would appear the results expressed in terms of "duty," including the standard based on one million heat units.

In the third subdivision of the second section, viz., that relating to locomotives, there would be two parts: one pertaining to shop tests and the other to road tests; and in both of these there would be the special data pertaining to the work of the locomotive, as formulated by the report of the committee on locomotive tests in vol. xiv. of the *Transactions*, including the standard of efficiency therein determined, viz., the quantity of so-called "standard coal" used per dynamometer horse-power per hour.

In the fourth subdivision of the second section, that relating to

engines for driving electric generators, data would be given embracing the quantity and intensity of the current generated, the electrical horse-power developed, and the efficiency of the generator. In the case of railway engines this would also include the current delivered to the motors on the line, and expressions of efficiency based on car mileage.

The fifth subdivision of the second part, that relating to marine engines, would present such data as pertain specially to marine work, such as the quantity of coal consumed and the results bearing upon it, the speed of the vessel, the slip of the screw, and the tonnage moved a given distance per unit of power.

The above is an outline giving the main features of one method of formulating the tabular reports so as to secure the objects in view.

Returning now to the methods of obtaining the data, one of the most important elements of data required is the quantity of work which the steam performs. The work done by the steam in an engine cylinder has in the past been ascertained, and probably will continue to be ascertained, by the use of the steam engine indicator. The reliability of this instrument is the foundation upon which a correct determination of the engine's efficiency rests. How the indicator should be applied, how it should be operated, how its springs should be calibrated, and how the diagrams which it produces should be read and investigated, are questions which should be settled by the proposed standard method of engine testing; and to these questions little attention has been given and little required at the hands of previous committees. It may not be out of place to recall the fact that there is no accepted method amongst engineers of calibrating indicator springs; and it seems to me that in the work suggested, investigation and recommendation should be made as to the best mode of dealing with this important subject.

If the suggested arrangement of the tabular reports be followed, they would be preceded by a similar arrangement of the methods laid down for determining the various data. In the first place, directions would be given for ascertaining the data of the first section, or that applying to all engines, whatever their type; and these would cover the ground with that completeness which characterizes previous reports. Much of the material applicable to engines in general, given in the reports of the duty trial and locomotive test committees, would appear in this section, and

would there be dealt with once for all. The second section would similarly be divided into the subdivisions named, and in each of the various subdivisions complete directions would be given for obtaining the special data applying to the individual case. In the matter of duty trials and locomotive tests, the subdivisions would deal with all the directions laid down in the previous reports.

I have thus indicated, in a very general way, what may be done to standardize engine tests covering all classes of machines, not with a desire to anticipate the action of a committee, should the Society see fit to appoint one, but rather to bring the subject to attention and "set the ball rolling."

DISCUSSION.

Prof. R. C. Carpenter.—I heartily concur with the suggestions made by Mr. Barrus in regard to the advantages which might result to the Society by the consideration of various methods of testing engines and by the adoption of standard methods for each case.

In addition to the advantages enumerated by Mr. Barrus, the writer would call attention to the desirability of expressing the results in a uniform manner. This is fully as important as the consideration of standard methods of performing the test, and would naturally form a part of the report of the committee.

The writer has given the matter considerable thought during the past few years in connection with the testing of various plants by advanced students in Sibley College, and has worked up a number of forms for reporting the results. These forms are naturally more or less imperfect, but are here submitted, believing that they may prove to be at least suggestive to the committee in charge of the proposed standard method of engine testing.

DEPARTMENT OF EXPERIMENTAL ENGINEERING—SIBLEY COLLEGE.

Report of Engine Test.

Made by.............. .... *Date*..................

Kind of Engine.................... *Mfg. by*.... ....

Duration of run.............. ......Hours		Diameter of cylinder............. ...inches.		
Revolutions per minute..........		Length of stroke.................... "		
Temperature condensing water, cold....F°		Diameter of piston rod .... "		
" " " warm.... "		Piston displacement, crank end....cubic ft.		
" condensed steam.......... "		" head " .... "		
" engine-room.............. "		Volume of clearance, " " ... per cent.		
" external air .... "		" " crank " ... "		
Boiler-pressure gauge ....lbs.		Maker of indicator		
Barometer.......................inches hg.		Spring..........................lbs. per in.		
Condenser .... "		Length of brake arm.... .. ..feet.		
Boiling temp., atmospheric pressure.....F°		Brake load......... ....lbs.		
Temperature of jacket water.... ...... "		Quality of steam at cut-off.................		
Total steam per hour, boiler test ......lbs.		" " release		
" " condensed ...... "		Steam-chest pressure gauge................		
Total jacket water per hr.......... .... "		Cut-off, crank end..........per cent. stroke		
" condensing water per hr...... .... "		" head " .... " "		
Wt. condensing water per lb. steam........		Release, crank " .... " "		
Total I. H. P............. ......,.........		" head " .... " "		
" D. H. P.......		Compression crank .... " "		
Mechanical efficiency.............per cent.		" head .... " "		
Moisture in steam.... .. .. "		Absolute pressure at point of cut-off....lbs.		
Steam per I. H. P. per hr. actual........lbs.		" " " release........... "		
" I. H. P. " corrected Cal. "		" back pressure................. "		
" D. H. P. " " "		I. H. P. head		
Steam H. P. hour of perfect engine..... "		I. H. P. crank.............................		
Thermodynamic efficiency		Total I. H. P		
Ratio actual to theoret. water consump.....		Steam per I. H. P. at point cut-off per Dia...		
Heat supplied per hour ....B. T. U.		" " " release " ..		
" discharged per hour.......... "		Jacket water....................lbs. per hr.		
" utilized per hour............. "		Per cent. of total jacket water..............		
B. T. U. per I. H. P. per min		Jacket-water receivers...........	1st	2d
Ratio or expansion.........................		Per cent. of total jacket water...............		
		Distribution of work. H. P. as 1..........		
		Heat received per minute..........B. T. U.		
		" equivalent of work per minute "		
		" discharged per minute........ "		
		" lost by radiation per minute.. "		

DEPARTMENT OF EXPERIMENTAL ENGINEERING—SIBLEY COLLEGE.

Test of Simple Engine built by................*Kind of Engine*................

Clearance, Head, per cent.......	Dia. Piston Rod, inches........	Date ....189..
" Crank, "	Piston Area, sq. inch, Head	Test made by ....
Scale of Spring	" " Crank....	....
Brake Arm.........................	Steam Port Area, sq. inch......	....
Dia. Cylinder, inches...........	Exhaust Port " "	....
Length Stroke...................	Dia. Fly Wheel, inches.........	....

		Rev'ons		Gauge Readings					Temperatures.									Weights.			
				Lbs.			In. Hg.								Calorim'er.						
Number	Time	Continuous Counter	Speed Indicator	Boiler....	Steam Pipe....	Steam Chest....	Condenser.. ..	Barometer....	External Air....	Engine Room.....	Condensed Steam ...	Injection Water....	Discharge Water....	Exhaust..........	Steam Pipe, I,	Ste'm Ch'st, II,	.... III.	Condensed Steam...	Injection Water....	Brake Load.......	Cu. ft. Inject'n Water....
0																					
1																					
2																					
3																					
4																					
5																					
6																					
7																					
8																					
9																					
10																					
11																					
12																					
13																					
14																					
15																					
16																					
17																					
18																					
19																					
20																					
Ave'ge.																					

MECHANICAL LABORATORY, SIBLEY COLLEGE, CORNELL UNIVERSITY.

Test of Triple Expansion Engine built by.., *N. Y.*

LOG OF TEST. *Kind of Engine*...... ....

Number	Time	Revol'ns: Continuous Counter	Revol'ns: Speed Indicator	Gauge R'd'ngs, Pounds: Boiler	Gauge R'd'ngs, Pounds: Steam Pipe	Gauge R'd'ngs, In. Hg.: Exhaust	Gauge R'd'ngs, In. Hg.: Condenser	Gauge R'd'ngs, In. Hg.: Barometer	Temperatures: External Air	Temperatures: Engine Room	Temperatures: Condensed Steam	Temperatures: Injection Water	Temperatures: Discharge Water	Temperatures, Calorimeter: Steam Pipe, I.	Temperatures, Calorimeter: Steam Pipe, II.	Temperatures, Calorimeter: Steam Pipe, III.	Temperatures, Calorimeter: IV.	Weights: Condensed Steam	Weights: Feed Water	Weights: Injection Water	Cu. ft. Injection Water	High Pr. Cyl., Hd.: M. E. P.	High Pr. Cyl., Hd.: I. H. P.	High Pr. Cyl., C'k.: M. E. P.	High Pr. Cyl., C'k.: I. H. P.	High Pr. Cyl.: I. H. P. Total	Int. Pr. Cyl., Hd.: M. E. P.	Int. Pr. Cyl., Hd.: I. H. P.	Int. Pr. Cyl., C'k.: M. E. P.	Int. Pr. Cyl., C'k.: I. H. P.	Int. Pr. Cyl.: I. H. P. Total	Low Pr. Cyl., Hd.: M. E. P.	Low Pr. Cyl., Hd.: I. H. P.	Low Pr. Cyl., C'k.: M. E. P.	Low Pr. Cyl., C'k.: I. H. P.	Low Pr. Cyl.: I. H. P. Total	Brakes, H. P.: Load	Brakes, H. P.: D. H. P.	Brakes, I. P.: Load	Brakes, I. P.: D. H. P.	Brakes, I. P.: Load	Brakes, I. P.: D. H. P.	I. H. P. Total	D. H. P. Total	Mechanical Efficiency	Pounds Steam per I. H. P. per hour
0																																														
1																																														
2																																														
3																																														
4																																														
5																																														
6																																														
7																																														
8																																														
9																																														
10																																														
11																																														
12																																														
13																																														
14																																														
15																																														
16																																														
17																																														
18																																														
Average																																														

HIGH PRESSURE CYLINDER.		INTERMEDIATE PRESSURE CYLINDER.		LOW PRESSURE CYLINDER.		TEST MADE BY
Clearance, Head, p. c...	Dia. Piston Rod, in....	Clearance, Head, p. c...	Dia. Piston Rod, in. ...	Clearance, Head, p. c...	Dia. Piston Rod, in....	....
" Crank, " ..	Piston Area, sq.in..Hd..	" Crank, " ..	Piston Area, sq.in.,Hd..	" Crank, " ..	Piston Area,sq.in.,Hd..	....
Scale of Spring........	" " " C'k..	Scale of Spring........	" " " C'k..	Scale of Spring........	" " " C'k..	....
Brake Arm............	Steam Port Area,sq.in..	Brake Arm............	Steam Port Area,sq.in..	Brake Arm............	Steam Port Area,sq.in..	....
Dia. Cylinder, inches...	Exhaust Port " " ..	Dia. Cylinder, inches...	Exhaust Port " " ..	Dia. Cylinder, inches...	Exhaust Port " " ..	....
Length Stroke..........	Dia. Fly Wheel, inches..	Length Stroke	Dia. Fly Wheel, inches..	Length Stroke..........	Dia. Fly Wheel, inches..	....

HIRN'S ANALYSIS—DATA AND RESULTS.

FORM III.

PER 100 STROKES.

Test by...189....

QUANTITIES.	Symbols.	FORMULÆ.	High Pressure.	Inter P.	Low P.
Steam from boiler, lbs	M				
Steam in clearance, lbs	M_c				
Steam used by calorimeter, lbs	M				
Steam, total, lbs	$M + M_o$				
Heat of condensed steam	K'				
Condensing water, lbs	G				
Heat given to condensing water	K				
Heat supplied to engine	Q				
Sensible heat at admission	H_o				
Internal heat at admission	H_o'				
Sensible heat at cut-off	H_1				
Internal heat at cut-off	H_1'				
Sensible heat at release	H_2				
Internal heat at release	H_2'				
Sensible heat, beginning of compression	H_3				
Internal heat, beginning of compression	H_3'				
Cylinder loss during admission	Q_a				
Cylinder loss during expansion	Q_b				
Cylinder loss during exhaust	Q_c				
Cylinder loss during compression	Q_d				
Heat discharged, and work	B				
Loss	D				
Loss	D'				
Steam supplied jacket	M_J				
Heat supplied jacket	H_J				
Heat discharged, jacket	H_J'				
Heat loss, jacket	Q_J				
Total loss, cylinder and jacket	D_J				
Heat loss, 1st receiver jacket	D_R				
Heat loss, 2d receiver jacket	D_R'				
Quality of steam entering	X				
Quality of steam at cut-off	X_1				
Quality of steam at release	X_2				
Quality of steam at admission	X_o				
Quality of steam in exhaust	X_5				
Heat lost, admission	a				
Heat restored, expansion	b				
Heat rejected, exhaust	c				
Heat lost, compression	d				
Heat utilized, work	w				
Heat lost, radiation	r				
Ratic, radiation to work					
Ratio, cyl. condensation to work					
Thermodynamic efficiency	E				
Actual efficiency	E_1				
Efficiency compared with ideal	E'				
Radiating surface of engine	S				
Loss per sq. ft. per hour	F				
Loss per sq. ft. per hour					
Loss per degree diff. tempt					

Mr. J. B. Stanwood.—Mr. Barrus in his paper classifies engines in accordance with their service. Group 4 embraces engines employed in generating electricity. I would suggest that attention be given to the determination of variations in steam consumption per indicated horse-power as affected by variations in load for engines of this group.

It is commercially important to determine for engines in this service what our electrical friend (in relation to dynamos) calls

the "characteristics." This is the relation between pounds of steam per indicated horse-power and the load-limit: $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, full load and over load.

Information is sorely needed to-day upon this point, in order that more exact knowledge may be obtained of the economical value of different types of engines employed in this service.

Mr. William T. Magruder.—Mr. Bryan Donkin mentions in his paper the subject of gas and oil motors, but omits them from his classification, and also omits the fourth division of Mr. Barrus's paper on engines employed in generating electricity. I should like to see not only this fourth class retained, but also a sixth class added to Mr. Barrus's suggestions, namely, those engines which are run by gas or oil. The engines in the five classes mentioned by Mr. Barrus are all based on physics, but with gas and oil engines we have to do not only with physics, but with chemistry, and those of us who have made accurate tests of gas and oil engines find that there is a large amount of difficult chemistry involved. Not only do we have the physical problems, such as the determination of the fuel and water consumption, the temperatures of the fuel, air and water and the like, but we also have the chemical problems of the calorimetry and analysis of the gas or oil and of the exhaust gases. If the problem of coal calorimetry has been a difficult task when a few grammes of coal are used for a sample, how much greater need is there for skill and accuracy when but a few milligrammes of the gas are used for a sample. Another special problem arises in the necessity for the invention and use of a continuous indicator. The need for such an indicator is brought about by the fact that both in the present "hit and miss" and in the throttling systems of governing we do not get the same initial pressure nor the same area of indicator cards in successive cycles or double strokes, so that it is possible to obtain high or low mechanical efficiencies, according to whether the cards taken were small or large ones. A similar problem arises in counting the number of explosions in order to determine the indicated horse-power, as it does not necessarily follow that the fuel is exploded or burned in all gas or oil engines every time a charge is taken. These are but a few of the many problems arising in the tests of these engines which do not obtain in the case of tests of steam engines. If this committee is appointed, I would therefore suggest that it be requested to also consider the addition of this sixth class to the five suggested by Mr.

Barrus, and that it formulate a standard method of testing gas and oil engines and report the same to this Society.

Mr. Chas. W. Barnaby.—There is one point in connection with the tests of engines that it seems to me should be covered by this system of standard tests, and that is the point of cut-off. The expert who conducts an economy test is frequently called upon to decide whether the dimensions of the cylinders on the engine are such as will give the specified power at the specified point of cut-off. The question is, What is the "point of cut-off"? A single cylinder engine is usually required to develop a given power, cutting off at $\frac{1}{4}$ stroke. Now, what is meant by $\frac{1}{4}$ cut-off? In the case of the Corliss engine, where the steam-line is carried out practically straight, we get a straight initial line and quite a sharp cut-off.

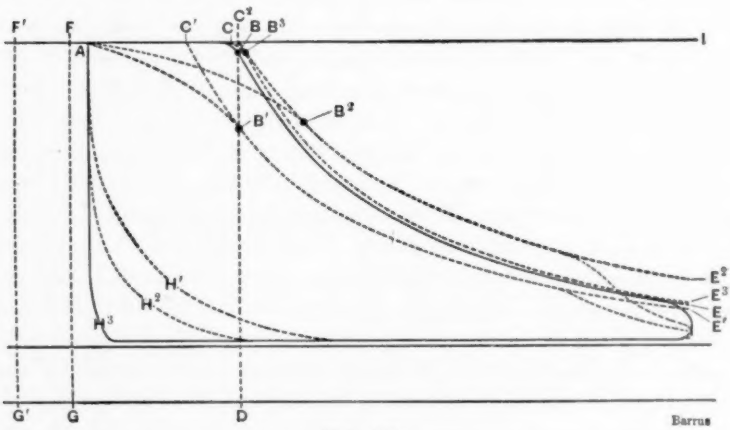

Fig. 171.

On the Corliss engine actual closure of the port at $\frac{1}{4}$ stroke will give very different results from those which would be obtained from the single valve engine, when the initial line is rounded down to a considerable dergee before the actual cut-off takes place. Fig. 171 illustrates this.

The idea is that, supposing the upper line (AB) to represent the admission line of a Corliss card, and the lower curve (AB') that of a single valve card, the point (B, B') of actual port closure being in both cases on the line (C^2D) representing $\frac{1}{4}$ stroke, it is evident that, taking the point of actual closure at $\frac{1}{4}$ stroke, we get a higher degree of expansion on the single valve engine than we do on the Corliss, leaving the clearance out of

consideration. Of course the extra clearance in the single valve engine has a tendency to raise the terminal pressure, and thus reduce the number of expansions; but I think that ordinarily, with an actual closure of the port at $\frac{1}{4}$ stroke, the terminal pressure of the single valve engine would be lower than the Corliss, thus giving a greater number of expansions on the single valve than on the Corliss engine.*

It therefore seems to me that the point of actual port closure is not the proper basis upon which to determine the rating of the engine. I take it that when $\frac{1}{4}$ cut-off is specified by the purchaser as the basis upon which the rating of the engines offered him is to be determined, he desires the economy corresponding with a theoretical $\frac{1}{4}$ cut-off rather than an actual closure of the valve at any particular point. In other words, that the point of cut-off should be at such point on the curve CE or CE^2 due to $\frac{1}{4}$ cut-off on a horizontal initial line as will give a rate of expansion which will correspond with a theoretical closure of the port at C^2. The important point is to secure economy by getting a certain degree of expansion. It is not material as to the exact point at which the valve actually closes. Therefore, if the standard method of conducting engine tests is intended to cover the determining of capacity as well as economy of engines, it seems to me that the manner of determining the point of cut-off should be established. Possibly it should be measured from the actual clearance line FG or $F'G'$. I am not quite clear as to the exact point from, and to, which it should be measured, and possibly that does not make so much difference, provided all parties understand what the point of cut-off is based upon, so that when a manufacturer guarantees that his engine will develop such a power at such a

*Upon platting out the cards in the above figure with about 3 per cent. clearance for the Corliss and 12 per cent. for the single valve engines, I find that the Corliss card $A\ B^3\ E^3\ H^2\ A$ and the single valve card $A\ B^2\ E^2\ H^2\ A$, each having an expansion corresponding with that which would result from a sharp cut-off at the $\frac{1}{4}$ stroke on the horizontal steam line AI and a point of actual port closure at B^3 and B^2 respectively, have practically the same area, giving some 41 pounds M. E. P. at 80 pounds initial pressure. On the other hand, if the point of actual closure is taken at $\frac{1}{4}$ stroke, at B and B', giving a Corliss card $A\ B\ E\ H^2\ A$ and a single valve card $A\ B'\ E'\ H'\ A$, the former will have about 40 and the latter only about 29 pounds M. E. P.; the rate of expansion being that which would be due to a cut-off at C, about .24 stroke, in the first case, and at C, about .16 stroke, in the second case.

I also find that the terminal pressure E' of the single valve card does fall below the terminal pressure E of the Corliss card, as I predicted at the meeting.

point of cut-off, he will know how it will be understood by the purchaser and the expert who conducts the test.

Prof. S. W. Robinson.—What should be considered the point of cut-off? I think there should be some such term as *effective cut-off* or *theoretical cut-off* laid down and established by this committee when its work is done. Undoubtedly that question has been up in the minds of many gentlemen here. Taking this diagram Fig. 172 as drawn, this curve *HFG*, for instance, is the

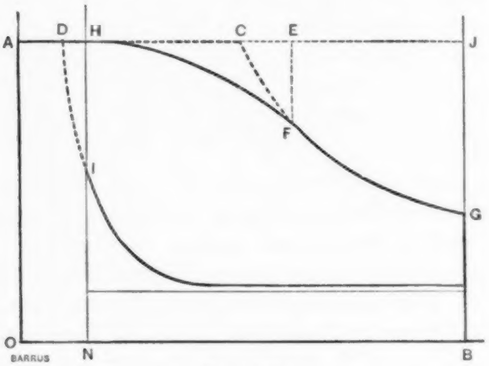

FIG. 172.

actual curve given by the indicator. Now, at some point near *F* the actual cut-off or actual closure of the valve occurred, so that the actual cut-off or the actual closure of the valve would be found by projecting a vertical line from *F* up to *E*. That point would be not far from where the counter-curvature at *F* occurs, and that is the point in the stroke of actual closure of the valve—but not the point of effective cut-off that I wish to call attention to. I think that some point *C* should be obtained by continuing the line *GF* back on some steam curve line *FC* to *C* to find the effective cut-off. That point should always be brought out in connection with tests. Attention is called to this important matter, and it is believed that the instructions to this committee that shall be appointed should be such as to require them to establish some point *C* as the true theoretical point of cut-off and defining the line *FC*, even in the case where there is considerable curvature *DF* of the actual indicator line.

Mr. Barnaby.—I would like to ask Mr. Robinson whether he would measure that point from the end of the card or from the clearance line; also as to whether the terminal pressure ought

not to be taken into consideration too. Of course either of those, I presume, would be sufficient. But it seems to me that either the clearance or the terminal pressure ought to be one of the elements; probably the terminal pressure would be better, because the varying amounts of compressions would affect the terminal pressure, while they would not have any particular bearing on the clearance. So that if the theoretical point of cut-off was taken in connection with the terminal pressure, there might be some satisfactory standard arrived at. My idea is that what we want to get at is the number of expansions, and that could be best got, probably, by taking in the terminal pressure as one of the elements.

Professor Robinson.—In answer to the question, if you will allow me a second word, the amount of steam admitted should not be taken as *HE* nor *HC*, but the compression line should be extended according to some steam lines from *I* to *D* to this top line. Now, the amount of steam admitted, I think, is *DC*, and that should be compared with the length *DJ* to obtain the ratio of expansion. As to what steam line *ID* should be, it is quite a question whether it should be the adiabatic steam line; but the curve to make on the board or on the diagram to establish *D* would be quite a question. There would be many points involved, such as the heat capacity of the cylinder walls, re-evaporation of steam, etc., just as in this curve *FC*.

Mr. A. Wells Robinson.—If this Society is to undertake the consideration of this subject, I should like to see it considered from two points of view. The first is the scientific point of view. I have no doubt that they will give that point of view every attention. The other point of view is that of the owner of the engine; and it seems to me that what we need to supply him with is some approximate system of obtaining just the information that he wants. It does not seem to me to be of much use to undertake a very elaborate system, to carry it out to, say, eight or ten places of decimals in an engine that is subject to a variation of 100 per cent. every five minutes; and what the owner of the engine wants to know in the majority of cases is the cost of his coal-pile, and how it can be reduced, if possible.

*Mr. George H. Barrus.**—I heartily concur in the suggestion of Professor Magruder to include gas and oil engines in the scheme

* Author's closure, under the Rules.

for the proposed standard system of testing, and I have no doubt that the committee will adopt his suggestion. The printed forms used at Sibley College, which Professor Carpenter submits, will be of value to the committee when they come to consider in what manner the tables of results had best be presented. The question as to the proper location of the point of cut-off on the diagram, brought up by Mr. Barnaby, is important, and this is one which should be settled by the proposed standards. I agree with Mr. Robinson that the matter under consideration should be viewed not only from the engineering standpoint, but also from the commercial standpoint. The interests of the owner and user of an engine should certainly be remembered, whatever action is taken.

As to Mr. Stanwood's suggestion, that it would be well to investigate the relative economy of engines at different loads, it seems to me that, although very desirable, this is work for an independent committee rather than for the one proposed.

NOTE BY THE SECRETARY.—Mr. Barrus's paper was presented and discussed in connection with the paper of similar tenor by Mr. Bryan Donkin, of London, England, entitled, "Extension of the Standard Uniform Methods of Conducting and Reporting Steam-Engine Tests." Readers and students are referred also to the discussion appended to that paper, which will be found as No. 786 of the current volume.

As the result of the discussion the Council was authorized and directed to appoint a committee to consider the question treated by Messrs. Barrus and Donkin. This committee, subsequently appointed, consisted of Messrs. Boyer, Barrus, Donkin, Jacobus, and Richmond.

DCCLXXXII.*

THE PROTECTION OF STEAM HEATED SURFACES.

BY C. L. NORTON, BOSTON, MASS.

THE investigation, of which this is a partial report, has been undertaken at the request of Mr. Edward Atkinson, and has been pursued during a large part of the years 1896 and 1897, and is yet uncompleted. The first object sought for was the relative efficiency of several kinds of steam pipe covering now upon the market. The second object was to ascertain the fire risk attendant upon the use of certain methods and materials used for insulation of steam pipes. Third, an attempt was made to show the gain in economy attendant upon the increase of thickness of coverings, and to show also the exact financial return which may be expected from a given outlay for covering steam pipes. Further information is given on many minor matters and conditions effecting the transfer of heat from a steam pipe to the surrounding air.

Method.

The method adopted is one which, so far as I know, is original. A piece of steam pipe is heated from the inside electrically. The amount of electrical energy supplied is measured, and hence the amount of heat furnished is known. If the steam pipe is kept at a constant temperature by a given amount of heat it is because that amount is just equal to the heat it is losing, for if the supply were not equal to the loss, the temperature would rise or fall. In other words, the heat put into the pipe is just equal to the heat lost from it by radiation, convection, and conduction. By measuring the electrical energy supplied I can determine the heat put in, and hence the heat given out or lost. It must be borne in mind that a given amount of electrical energy always produces the same definite amount of

* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

heat, the amount of heat furnished by one electrical unit of energy being known with greater accuracy than the amount of heat given out by a pound of steam in condensing.

Apparatus.

The apparatus for making tests by this method comprises several pieces of steam pipe of different diameters and lengths, heated electrically from within by means of coils of wire in oil. The oil is stirred vigorously, and serves as a very efficient carrier of heat from the wires to the pipes. A brief description of the smallest tester may make the details of the apparatus more easily understood.

A section is shown in Fig. 173.

A piece of 4-inch steam pipe, 18 inches long, is closed at one end by a plate welded in, and at the other by a tightly fitting cover. This pipe is then filled with cylinder oil, and a coil of wire of sufficient carrying capacity and a stirrer are introduced into the oil. A thermometer is inserted in such a position as to record the temperature of the oil. An ammeter and voltmeter or a wattmeter may then be connected so as to record the amount of electrical energy supplied. The stirring must be brisk, and if enough power is put into the stirrer to be comparable with the electrical energy supplied, such amount must, of course, be added, as it also is converted into heat. It is my custom to suspend the apparatus in the middle of the room on non-conducting cords, and read the thermometer with a telescope, so that no heat from the person of the observer may be added to the supply given to the cover from within, and also that care may be taken not to produce air currents by walking near the apparatus during a test.

Procedure.

In making a test the following operations are carried out, and observations are taken in the following order:

The current is turned on, and heat is generated in the wire coil until the wire, oil, and steam pipe have reached the desired temperature at which it is proposed to test. The current is then gradually diminished until it is found to be of just the amount necessary to keep the pipe at this temperature without a rise or fall of $\frac{1}{10}$ of a degree in 30 minutes. A reading of the

voltage and current is now taken at intervals of 30 seconds, and the watts and B. T. U. are computed from their average. We then have the number of B. T. U. lost from the outside of this particular pipe at this particular temperature. If now we place a steam pipe cover around the pipe, we shall find that a less

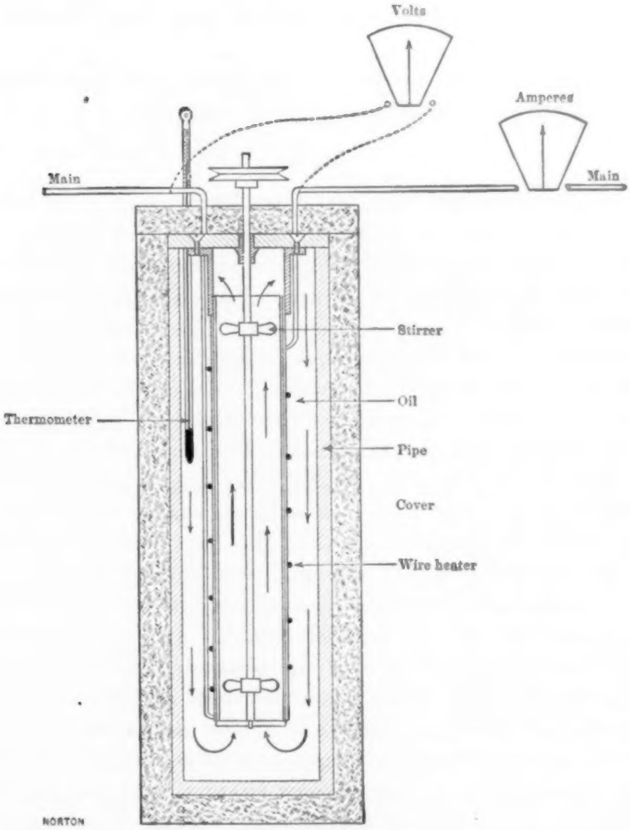

Fig. 173.

amount of energy is sufficient to keep it at the required temperature, the difference being the amount of heat saved by the covering. The minimum length of time considered sufficient for the equalization of heat or "soaking in" to the cover is six hours. If, after a second heating of six hours, no change in the conducting power is noted, the cover is considered in a per-

manent condition, and is tested. Some covers, notably those composed wholly or in part of wool, cannot be considered dry and constant until after an exposure upon a pipe at 200 pounds pressure for six or eight days. Covers containing sulphate of lime are also slow in drying.

The three thermometers used were frequently standardized in naphthaline, and were examined to note any disagreement among themselves.

A discussion of the position of the tester and its exposure to air currents will be found in a later paragraph.

Results.

A comparative test was made in 1895 upon a number of steam pipe covers on a 4-inch tester 16 inches long. The results obtained have been published in the circulars issued by the Boston Manufacturers' Mutual Fire Insurance Company and by the Steam Users' Association. The values were stated to be purely *relative*, the specimen being too small to give reliable data on the *absolute* conduction, and the surrounding conditions not being controlled other than to maintain them constant during the several runs. The ends of the specimen were covered by massive heads, and the whole tester was situated within a few inches of a brick wall and a stone pier. It was called to my attention that the heat loss was probably high, and I agree that the exposure was such as to make it so, being a rather harsh test, but one which was rigidly uniform in its requirements of the several covers. In short, the actual loss of heat per square foot of the pipe surface was correct for that particular piece under the conditions of the test, but was not sufficient for the estimation of the actual saving which might be expected from the general use of coverings. I deemed it wise, therefore, to construct new heaters, four and ten inches in diameter and thirty-six inches long. These were suspended by non-conducting cords in the centre of the laboratory, so as to hang freely and not be in contact with any conducting supports. Conduction up the lead wires and stirring rod was found to be negligible.

It seems to me that I have approached more nearly the conditions of actual practice that can be obtained by any other method of testing, except the actual use of a long run of pipe; and the determination of the amount of heat put into such a

pipe by the "condensation" method offers many difficulties and is open to much uncertainty. I feel, therefore, that in adopting this method I am using a reasonable exposure for the pipe, and have an exceptionally good opportunity to measure the heat supplied.

The general appearance of the testing apparatus is shown in Fig. 174. Table I. gives the relative conductivity of the various kinds of steam pipe cover tested up to April, 1898.

It gives the results of the tests upon most of the samples tested, some being omitted when found to be of such low efficiency as to be of doubtful value.

TABLE I.

Specimen.	Name.	B. T. U. Loss per Sq. Ft. Pipe Surface per Min.	Ratio of Loss to Loss from Bare Pipe.	Thickness in Inches.	Weight in Ounce per Ft. of Length 4 In. Diam.
A	Nonpareil Cork Standard	2.20	15.9	1.00	27
B	" " Octagonal	2 38	17.2	.80	16
C	Manville High Pressure	2.38	17.2	1.25	54
D	Magnesia	2.45	17.7	1.12	35
E	Imperial Asbestos	2 49	18.0	1.12	45
F	W. B.	2.62	18.9	1.12	59
G	Asbestos Air Cell	2 77	20.0	1.12	35
H	Manville Infusorial Earth	2.80	20.2	1.50	....
I	" Low Pressure	2.87	20.7	1.25	....
J	" Magnesia Asbestos	2.88	20.8	1.50	65
K	Magnabestos	2.91	21.0	1 12	48
L	Moulded Sectional	3.00	21.7	1.12	41
O	Asbestos Fire Board	3.33	24.1	1.12	35
P	Calcite	3.61	26.1	1.12	66
	Bare Pipe	13.84	100	....	....

Specimen A consists of granulated cork pressed in a mould at high temperature, and then submitted to a fire-proofing process.

Specimen B is similar in composition, but is made up of several strips of cork instead of two semicylindrical sections.

Specimen C is a sectional cover composed of an inner jacket of earthy material and an outer jacket of wool felt, the whole being one and one-quarter inches thick.

Specimen D is a moulded sectional cover composed of about ninety per cent. carbonate of magnesia.

Specimen E is essentially an air cell cover, being composed of sheets of asbestos paper which has been indented before being laid up, the indentations serving to keep the thin sheets of paper from coming in close contact with one another, thereby causing a considerable amount of air to be held throughout the body of the cover.

Specimen F is composed of a wool felt with a lining of asbestos paper.

Specimen G is a cover made up of thin sheets of asbestos paper fluted or corrugated and stuck together with silicate of soda.

Specimen H is a plastic covering made of infusorial earth.

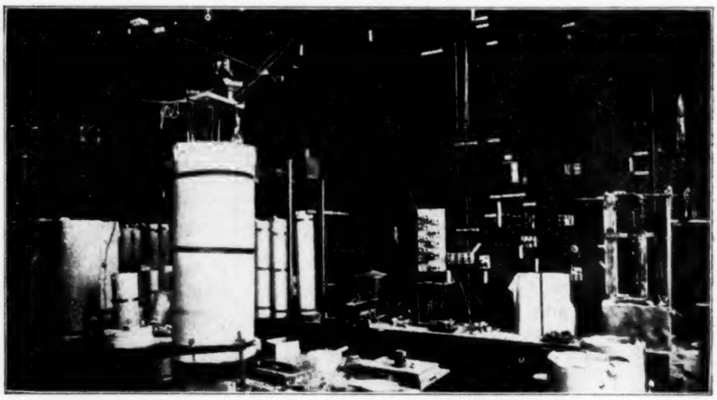

Fig. 174.

Specimen I is a low pressure covering similar to Specimen F.

Specimen J is a plastic cover, and called by the makers magnesia asbestos. It contains only a slight amount of carbonate of magnesia.

Specimen K.—The magnabestos is a moulded cover, containing about 45 per cent. of carbonate of magnesia and a considerable percentage of carbonate of lime.

Specimen L is composed mainly of sulphate of lime and some twenty per cent. of carbonate of magnesia, and has upon its outer surface a thick sheet of felt board.

Specimen O is similar to Specimen G, except that it has larger cells and contains much more silicate of soda. It is very hard and strong.

Specimen P is a sectional moulded cover, composed mainly of sulphate of calcium. It has an outer layer of felt board.

In regard to the compositions of specimens C, J, L, and P, I desire to state that I have made no complete analysis, but have satisfied myself that the principal ingredient is sulphate of calcium and *not* carbonate of magnesia. Prospective purchasers of pipe covers should not be misled by names. Since the appearance of Professor Ordway's reports it has been recognized that carbonate of magnesia was of great value as a non-conductor of heat, hence the name " magnesia " has been applied to a great many covers. It is to be observed that there is no virtue in a name. Asbestos is merely an incombustible material in which air may be entrapped, but when not porous is a good conductor of heat. Magnesia is a most effective non-conductor. This name has been applied to many compounds of which the greater part consist of carbonate of lime, or plaster of Paris, materials which are not good as a heat retardant. The percentage of magnesia carbonate and plaster of Paris in several moulded sectional covers is given in Table II.

I have made no investigation of the effect of the raw materials upon the metal of the pipe other than to satisfy myself that the cork, magnesia, air cell and Imperial covers cause no corrosion.

TABLE II.

Specimen.	Percentage Composition.	
	$Mg. CO_3$.	$Ca. SO_4$.
D....	80 to 90	3
C....	less than 5	65 to 75
L....	20 to 25	50 to 60
P....	less than 5	75
J....	10 to 15	none.

The conditions of testing were such as I have adopted as being reasonably near the conditions of actual practice. The room temperature was kept at 72 degrees Fahrenheit, and the openings into the room were carefully closed. It was found early in the series that variation in the amount of moisture present in the air altered the amount of heat lost from the covers, but no attempt was made to correct for this. The error introduced is not greater than one per cent.

It was found that the heat loss per square inch of the flat surfaces at the ends of the pipes was less by several per cent. than the loss from the sharply curved sides, and as all pipe covers tested were used to cover both sides and ends, the figures given in the table show a loss less than would be shown were the pipe surface wholly cylindrical, and more than if it were all flat.

The pipes were suspended from the ceiling, as described in an early paragraph, and the air circulating about them was due only to their own convection currents. The variation in thickness in different places on the same specimen was considerable, but an average of twenty measurements was taken and results given in the table to the nearest one-eighth of an inch. Owing to these variations in thickness, the results of a measurement of the efficiency of any one cover cannot be used to predict the efficiency of a second cover of the same make with an accuracy greater than two per cent. Two specimens of each make were tested, and in some cases four, the mean value being given in the table.

Table III. gives the saving, in dollars, due to the use of the various covers.

Table IV. shows that at the end of ten years the best of the covers tested will have saved $46 more than the poorest. The difference between the several covers of the better grade is exceedingly small.

The money saving is computed on the following assumptions. Coal at $4 a ton evaporates ten pounds of water per pound of coal. The pipes are kept hot ten hours a day three hundred and ten days a year. If computations are made, as is sometimes done, on an assumption that the pipes are hot twenty-four hours a day three hundred and sixty-five days in a year, the saving is nearly three times that shown in Table III.

Generally speaking, a cover saves heat enough to pay for itself in a little less than a year at 310 ten-hour days, and in about four months at 365 twenty-four-hour days.

It is evident that the decision as to the choice of cover must come from other considerations, as well as from the conductivity.

The question of the ability of a pipe cover to withstand the action of heat for a prolonged period without being destroyed or rendered less efficient is of vital importance. The increasing

use of cork as an insulator has led to many questions as to its ability to remain "fire proof." I have exposed it to a temperature corresponding to 350 pounds of steam for three months,

TABLE III.

Specimen.	Name.	Loss B. T. U. 200 lbs.	Saving B. T. U.	Saving per year per 100 sq. ft.
A	Nonpareil Cork Standard	2.20	11.64	$37.80
B	Nonpareil Cork Octagonal	2.38	11.46	37.20
C	Manville Sectional, H. P.	2.38	11.46	37.20
D	Magnesia	2.45	11.39	36.90
E	Imperial Asbestos	2.49	11.35	36.80
F	"W. B."	2.62	11.22	36.40
G	Asbestos Air Cell	2.77	11.07	36.00
H	Manville Infusorial Earth	2.80	11.04	35.85
I	Manville Low Pressure	2.87	10.97	35.65
J	Manville Magnesia Asbestos	2.88	10.96	35.60
K	Magnabestos	2.91	10 93	35.50
L	Moulded Sectional	3.00	10.84	35.20
O	Asbestos Fire Board	3.33	10.51	34.20
P	Calcite	3.61	10.23	33.24
	Bare Pipe	13.84	0.00	

TABLE IV.

NET SAVING PER 100 SQ. FT.

SPECIMEN.	NAME.	1 YEAR.	2 YEARS.	5 YEARS.	10 YEARS.
A	Nonpareil Cork Standard	$12 80	$50 60	$164 00	$353 00
B	Nonpareil Cork Octagonal	12 20	49 40	161 00	347 00
C	Manville Sectional High Pressure	12 20	49 40	161 00	347 00
D	Magnesia	11 90	48 80	159 50	344 00
E	Imperial Asbestos	11 80	48 60	159 00	343 00
F	"W. B."	11 40	47 80	157 00	339 00
G	Asbestos Air Cell	11 00	47 00	155 00	335 00
H	Manville Infusorial Earth	10 85	46 70	154 25	333 00
I	Manville Low Pressure	10 65	46 30	153 75	331 00
J	Manville Magnesia Asbestos	10 60	46 20	153 00	331 00
K	Magnabestos	10 50	46 00	152 50	330 00
L	Watson's Moulded Sectional	10 20	45 40	151 00	327 00
O	Asbestos Fire Board	9 20	43 40	146 00	317 00
P	Calcite	8 24	41 48	141 20	307 00
Q	Bare Pipe	....	....	....	....

and to a temperature corresponding to 100 pounds for two years, and can detect no change, and I am satisfied, as well as one can be without the actual experience, that any suspicion of its ability to withstand continued heating is groundless.

The magnesia covering is, of course, unquestionable on this ground, being almost indestructible by heating.

The Imperial asbestos is also perfectly safe from any fire risks, as is the air cell and fire board.

The Manville infusorial earth and also the Manville asbestos magnesia are liable to no accident from fire, nor is the Carey calcite.

It is to those covers, the "W. B." of the Watson Co., and the Manville sectional and others which possess a composite structure, that I desire to call attention. I do not consider it safe to put upon a steam pipe wool, hair, felt, or woollen felt in any form. The causes of risk are two: First, the wool may become charred by heat from the pipe and finally ignited. However, this can hardly happen, even on high-pressure pipes, when the thickness of fire-proof material, asbestos, magnesia, or whatever it may be, is of as great a thickness as one inch. The second and most serious risk is from the presence in shops or mills of the long tubes of wool, dry as tinder, often connecting one room with another, and ready to flash at the slightest rise in the already too great temperature. I would even insist that the canvas jackets on the covers be fire-proof. An accident in my own laboratory has proved the actual danger of these wool felts, and I should not be willing to allow their use again. Their efficiency is high as non-conductors, but not higher than any other perfectly safe covers. If the wool is separated by about one inch of fire-proof material from the pipe it is not kept so hot and dry, and the risks from outside ignition are less; but I do not endorse the practice of many engineers in wrapping hair felt outside of a sectional cover. The saving due to this practice is indicated in Table V.

The following assumptions have been made in computing the Tables IV., V., and VI. First, that all the covers cost $25 per one hundred square feet applied. I realize this is a high figure, perhaps too high, yet it is not far from the list price of several makers, and any attempt to get a definite price from them revealed a maze of discounts and double discounts and flexible price lists too intricate for an uninitiated mind to travel. In case the saving due to a cover which costs $20 instead of $25 is desired, the simple addition to the final saving of the $5 difference makes the necessary correction.

Secondly, by the advice of the makers, I have made an as-

sumption that the cost is not nearly proportional to the thickness. As the thicker coverings are not now made in great quantities, the actual cost of their manufacture is uncertain.

TABLE V.

VARIATIONS IN THICKNESS, ETC.

Specimen.	Saving in B. T. U. per sq. ft. per minute.	Saving in dollars per 100 sq. ft. per year.	Net Saving.				Approximate cost.
			1 year.	2 years.	5 years.	10 years.	
Magnesia :							
1⅜ inches thick	11.62	$37 75	$7 75	$45 50	$159	$347	$30
Magnesia, 1⅜ inches thick and 1 inch of hair felt	12.38	40 22	5 22	45 44	166	367	35
Magnesia, 1⅜ inches thick and 2 inches of hair felt	12.77	41 50	1 50	43 00	167	375	40
Nonpareil cork :							
1 inch	11.64	37 80	12 80	50 60	164	353	25
2 inches	12.84	41 75	7 75	48 50	174	383	35
3 inches	12.94	42 05	7 95	34 10	160	370	50
Fire board :							
1 inch	10.54	34 20	9 20	43 40	146	317	25
2 inches	11.48	37 25	2 25	39 50	151	337	35
3 inches	11.70	38 00	12 00	26 00	140	330	50
4 inches	11.83	38 40	26 60	11 80	127	319	65

Inspection of Table V. shows the saving due to the use of hair felt outside a standard magnesia cover.

In five years 100 square feet of hair felt saves $7 more than its cost, and in ten years it saves $20 above its cost.

The further saving due to a second inch outside the first is $8 in ten years. Of course the well-known tendency of hair felt to deteriorate should be considered.

In the case of Nonpareil cork, increasing the thickness from one to two inches raises the cost from about $25 to $35 per 100 square feet, and increases the net saving in five years by $10, and by $30 in ten years. In other words, the second inch of material in use about pays for itself in two years, while the first pays for itself in about one year. The third inch does not increase the saving even in ten years. The second inch, therefore, more than pays for interest and depreciation, while the third fails to do this.

In the case of the asbestos fire board, a second inch in

thickness causes a saving of $20 in ten years, the third and fourth inches showing a loss.

In general it may be said, therefore, that if five years is the length of life of a cover, one inch is the most economical thickness, while a cover which has a life of ten years may to advantage be made two inches thick.

In view of the custom which prevails to some extent of wrapping asbestos paper around a pipe, and surrounding the whole with hair felt, I made tests as to the temperature of the bounding line of the asbestos paper and hair felt, using a Le Chatèlier thermo-electric pyrometer for this purpose. The different samples of asbestos paper give widely varying results, but a general idea of the protection offered by the paper may be had from Table VI.

TABLE VI.

PROTECTION AFFORDED BY ASBESTOS PAPER.—PIPE AT 200 POUNDS PRESSURE.

Thickness of Asbestos Paper.	Temperature of Pipe.	Temperature of Inside of Hair Felt.	Pressure Corresponding to the Temperature of the Inside of the Hair Felt.
$\frac{1}{64}$ inch.	384.7° Fahr.	356° Fahr.	146 pounds.
$\frac{1}{32}$ "	385.0° "	329° "	102 "
$\frac{1}{16}$ "	384.6° "	302° "	70 "
$\frac{1}{8}$ "	384.7° "	266° "	39 "

I have had my attention called to the varying loss from bare pipes when their surfaces were in varying conditions as regards rust, dirt, paint, etc. I therefore made a few brief tests to satisfy my mind as to the chance of there being any large variation which might influence my figure for the loss from bare pipe, viz., 13.84 B. T. U. per square foot per minute. The results are shown in Table VII.

TABLE VII.

LOSS OF HEAT AT 200 POUNDS FROM BARE PIPE.

Condition of Specimen.	B. T. U. Lost per sq. ft. per minute.
New pipe	11.96
Fair condition	13.84
Rusty and black	14.20
Cleaned with caustic potash inside and out	13.85
Painted dull white	14.30
Painted glossy white	12.02
Cleaned with potash again	13.84
Coated with cylinder oil	13.90
Painted dull black	14.40
Painted glossy black	12.10

The rate of heat loss from a bare pipe is also affected by the air circulation and the temperature of the surrounding bodies. A few tests were made to indicate the magnitude of the errors likely to be caused by variation in these conditions, and a brief examination of some of the results may be interesting. They are given in Table VIII.

TABLE VIII.

EFFECT OF SURROUNDINGS.

Condition and Position of Pipe.	B. T. U. lost per sq. ft. per minute at 200 pounds.
1. Standard condition hung in centre of room..........	13.84
2. Near brick wall, between windows	14.26
3. Hung horizontally in centre of room...............	12.06
4. Vertical 10-inch pipe { 36 inches long..............	13.48
4. Vertical 10-inch pipe { 18 inches long..............	14.42
5. Vertical, 18 inches long { 10 inches diameter	14.42
5. Vertical, 18 inches long { 4 inches diameter	15.20
6. 4 inches diameter in draft from electric fan	20.10

Table IX. shows the varying loss from a bare pipe with the change in pressure :

TABLE IX.

VARIATION OF HEAT LOSS WITH PRESSURE.

Pressure.	Bare Pipe. Loss B. T. U. per sq. ft. per min.
340	15.97
200	13.84
100	8.92
80	8.04
60	7.00
40	5.74

A very thorough test was made of the common method of judging a pipe cover by the sensation of warmth given the hand on touching it, and nothing too harsh can be said of this practice. The sensation is dependent to such an extent upon the *nature of the surface* that it fails utterly to give any idea of the actual temperature. I have been unable to devise any method of so attaching a mercury thermometer to the outside of a steam-pipe cover as to make use of it as a testing device in measuring heat loss.

I am desirous of calling attention to the advantages arising from the use of plastic rather than sectional covers. The ease of removal for repairs or alterations makes the sectional cover better for some work, but there is much pipe surface which might be covered securely with plastic where a sectional cover

is soon ruined by vibration. Of course the plastic covers offer no possibility of leaky joints and long cracks. It should be borne in mind that in most cases about twenty per cent. of the entire surface to be covered is irregular, and must be covered by plastic or fittings. It will be well for prospective purchasers of pipe cover to see to it that their contracts call for fittings and plastic of as high an efficiency as the sectional cover shows.

I am now testing a considerable number of samples of non-conducting material, not perhaps classed as pipe covers, but used for heat insulation. Table X. gives some figures concerning them which may be of interest.

TABLE X.

MISCELLANEOUS SUBSTANCES.

Specimen.	B. T. U. per sq. ft. per min. at 200 lbs.	Saving in one year per 100 sq. ft. pipe.
Box A.		
1 with sand	3.18	$34 60
2 with cork, powdered	1.75	39 40
3 with cork and infusorial earth	1.90	38 90
4 with sawdust	2.15	37 90
5 with charcoal	2.00	38 50
6 with ashes	2.46	36 90
Brick wall 4 inch thick	5.18	28 80
Pine wood 1 " "	3.56	33 80
Hair felt 1 " "	2.51	36 80
Cabot's seaweed quilt	2.78	35 90
Spruce 1 inch thick	3.40	33 90
" 2 " "	2.31	37 50
" 3 " "	2.02	38 50
Oak 1 inch thick	3.65	33 10
Hard pine 1 inch thick	3.72	32 90

The box A referred to in the table is a $\frac{7}{8}$-inch pine box, large enough to surround the pipe, and leave a one-inch minimum space at its four sides. In it were tested several materials which I find are used in just this way for steam and cold storage insulation.

In concluding, I desire to express my thanks to those gentlemen who have assisted me in this test, and especially to Mr. John R. Freeman, member of the Society, for his kindly advice.

DISCUSSION.

Prof. R. C. Carpenter.—As I understand the description given in the paper by Mr. Norton the results which he has recorded and which are obtained, doubtless with considerable accuracy, show the amount of heat which will flow from a given mass of heated oil

through the surrounding bodies to air. I cannot as yet bring myself to believe that this will give us any valuable information as to the amount of heat flow which would take place under similar conditions from steam to air, although it is possible that the comparative results may be the same. The reasons for questioning these results are due to the fact that I had, at one time, some experiments made in which the flow of heat was made to take place between different media, but in every case through the same plate of metal. The media employed were steam and water, lard oil and water, and air and water. The results in each case varied exceedingly with the character of the medium giving off the heat, and I am not as yet prepared to believe that oil will surrender its heat at the same rate as steam.

The following table gives the results of the experiments referred to, reduced to the flow per square foot, per degree difference of temperature and total per minute. The difference in rate of flow of heat of steam to air as compared with oil to air would doubtless be less than found in the conditions shown in the table, but the writer believes this difference would be considerable and sufficient to practically affect the results.

HEAT TRANSMITTED IN THERMAL UNITS THROUGH CLEAN CAST-IRON PLATE $\frac{7}{16}$ INCH THICK.

Difference of Temperature. Degrees F.	Steam to Water. Per Sq. Foot.		Lard Oil to Water. Per Sq. Foot.		Air to Water. Per Sq. Foot.	
	Per Degree per hour B. T. U.	Total per minute B. T. U.	Per Degree per hour B. T. U.	Total per minute B. T. U.	Per Degree per hour B. T. U.	Total per minute B. T. U.
25	21	8.8	6.5	2.7	1.2	0.5
50	48	40	13	10.8	2.5	2.7
75	84	110	19.5	24.5	3.7	5.8
100	127	211	26	43.3	5.0	8.3
125	185	375	31.5	65.5	6.2	13
150	255	637	39	72.5	7.5	18.7
175			45.5	132	8.7	25.4
200			52	173	10	33
300			78	390	15	75
400					20	133
500					25	208

The above investigation indicates that the substance which surrenders the heat is of material importance, as is also the temperature of the surrounding media.

I have spent considerable time in making experiments relating to the flow of heat from steam to air through pipes under various conditions, and I have also given considerable time to the study of the reports from other experiments. There is a considerable discrepancy in the various reports which have been given, and the writer at one time believed that these could be accounted for by errors in the measurements of heat supplied, but my own investigations have caused me to believe that, while some errors have resulted in certain cases from the practice followed, the principal errors were due to the change in condition of the surrounding air. I am fully satisfied that the amount of heat which is given off from a steam pipe may vary from 200 to 300 per cent., depending upon the rate of motion of the air and its hygrometric condition, and I fully believe that differences of 5 to 19 per cent. may be caused by changes in air currents which are almost imperceptible to the observer.

For these various reasons I cannot help but believe that accurate information of the heat losses of steam pipes should be made under conditions which at least approximate to those of actual use.

Mr. William H. Bryan.—The exhaustive data presented in Mr. Norton's paper are of the greatest value to the profession, particularly those who are interested in the installation of steam plants. Every manufacturer of steam-pipe covering claims to have the best, and, in far too many cases, the lowest bidder gets the work and furnishes a relatively inferior covering.

Two kinds of cork covering are reported upon: the standard and octagonal, the only difference appearing—from Mr. Norton's paper—to be in their shape and make-up. I have always understood, however, that the standard was the higher-priced covering, and having been treated to make it fire-proof, was recommended for high-pressure work, while the octagonal was a cheaper covering, not having been treated at all.

I have used the cork covering with good results, but cannot yet speak personally of its durability. I was much surprised, however, to be shown recently a strip of the standard cork covering which had been noticeably charred in about fifteen months' service, and was, furthermore, warped out of shape to a considerable degree. I could not learn that this piece was faulty in its manufacture or that it had been subjected to unusually severe usage. This has somewhat dampened my high opinion of it, but

I am in hopes that this covering may prove itself to be an addition to our list of high-grade reasonably priced coverings.

Cork should not, of course, be used on smoke-flues or other highly heated surfaces.

Tables III. and IV. are based on coal costing \$4.00 per ton, and evaporating 10 pounds of water per pound of coal. With coal costing \$1.50 per ton and evaporating $7\frac{1}{2}$ pounds of water, as is the case in St. Louis and vicinity, these savings would be exactly one-half those given in the tables. I hope that Professor Norton may be able to give us at some future date somewhat more exact figures of the cost of coverings than stated in Table V.

Mr. H. H. Suplee.—Referring to the last remark of Professor Carpenter's, concerning the test of actual use, I was informed some time ago that the original discovery of the use of carbonate of magnesia as a non-conductor occurred in a chemical works where one of the magnesia salts was being made for medical purposes, and where they had occasion to dry materials by coils of steam pipe. They found, unless they kept the pipes very carefully dusted off, that a very slight coating of magnesia dust would settle on them and deprive them of nearly all their power as drying coils, and from that came the idea of using magnesia to keep the heat in the pipes.

I want to say one word in confirmation of Mr. Norton's idea of not judging temperature by the sense of touch. It depends not only on the surface of the material, but on the condition of your hand at the time, whether it is warm or cold. That can easily be shown by a simple experiment. By placing one hand in a bowl of warm water and the other in a bowl of cold water, and after leaving them there a few moments put them together in a bowl of water of the temperature of the room, that water will feel quite cold to one hand and quite warm to the other. That will convince one of the impossibility of judging the relative temperature by sense of touch, except in a very imperfect degree.

Mr. Henry C. Meyer, Jr.—Professor Norton, in his paper, calculates the saving that would follow the use of each covering which he tested at the end of two, five, and ten years, evidently basing the calculation upon the assumption that the heat transmitted by each covering remains constant. Unfortunately all pipe coverings do not retain their durability, and it is just this quality which makes it necessary to look farther than the mere

non-conductiveness of a covering when new, when in the market for such a material. A number of coverings when new will give a high efficiency, and yet these same coverings, after being subjected to the vibrations that usually occur in steam pipes, and to the moisture which may escape from leaky pipe joints, will, in the course of time, be very much less effective as non-conductors. Although the results of such a test may not be available for some time, yet I think that Professor Norton would add greatly to the value of his paper if he would supplement it by another, giving the results of further tests upon these same coverings at the end of one or two years, placing them, in the mean time, upon steam pipes where they will be subjected to common usage. If such tests were made I believe that Professor Norton would find cause to alter the figures materially which he gives for the savings that would be realized at the ends of the long periods he mentions.

There is a point in regard to the selection of many of those coverings sold as "magnesia" and "asbestos," to which it may be well to refer at this time. The great demand for pipe coverings on the part of our mills, electric plants, and particularly our large office buildings, has resulted in placing on the market a number of pipe coverings commonly called "magnesia" and "asbestos" coverings, and, although they are made of magnesia or asbestos, they are frequently not the kind of magnesia or asbestos which the purchaser supposes them to be. To make a cheap covering to meet competition, those good non-conductors, carbonate of magnesia and asbestos fibre, have been mixed with products which are cheaper and less effective as non-conductors. There is, of course, no harm in doing this, provided the true composition of the covering is made known, but I believe they should not be sold as magnesia or asbestos coverings when perhaps they contain but a small percentage of those materials. Asbestos is a natural rock, which, when crushed, produces asbestos fibre, the part which ought to be used in pipe coverings, and asbestos refuse, the "culm" of the operation. Sometimes the asbestos refuse is mixed with carbonate of lime, a harmless but inferior non-conductor, or with plaster of Paris. Some purchasers object to a covering containing plaster of Paris, but raise no objection when they are told it contains sulphate of lime. It may be well, therefore, to state that they are one and the same thing. Sulphate of lime is an inferior non-conductor and is apt to corrode the pipes if moisture is present owing to the sulphuric acid which would then form.

The cost of plaster of Paris is less than 10 per cent. of the cost of carbonate of magnesia or asbestos fibre; carbonate of lime costs about one-quarter as much; hence their use.

Magnesia coverings are also cheapened by mixing sulphate or carbonate of lime with the carbonate of magnesia, which, as Professor Norton points out, is a most effective non-conductor. Asbestos contains a good deal of silicate of magnesia, and asbestos refuse has been taken and mixed with sulphate of lime and soda as a magnesia covering. The terms "magnesia" and "asbestos" really mean little therefore, and are about as indefinite terms to put into a specification as the word "cement." If carbonate of magnesia is wanted it should be asked for, and the percentage of carbonate of magnesia wanted in the covering distinctly specified. If asbestos of the best grade is desired, specifications should call for a covering made wholly of asbestos fibre. Any one, I believe, can make it. Certainly there is no reason why the best covering should not be used, especially as it pays for itself in about three months, as Professor Norton's interesting paper shows.

Mr. John E. Sweet.—I have only one remark to make, and that is to give an account of our experience with covering. We are making a steam separator in which we cover the outside with lagging of one kind and another. We have tried asbestos, cork and magnesia in the form of staves, put on cement, etc. Then we covered the outside with Russia iron or planished steel. We find the steel on the outside after a while just about as hot as the pipes before the covering is put on. That we cannot account for. It does not seem to make any difference what we put on the outside; the steel eventually gets about as hot as the pipe.

Prof. S. W. Robinson.—In accounting for that, I think the polished character of the surface enters largely into account. Planished surfaces and bright surfaces radiate very much slower than rough or black surfaces, and there being no chance for the heat to go back after it has once reached the surface and having no chance to go forward on account of the brightness, it would seem that the plate must necessarily get hot. I noticed a case once in the Post Office in Boston, where there is an engine for driving their machinery for marking letters, and so forth, and a pipe about five inches in diameter brought the steam for the engine. This pipe was highly polished iron. I walked back and forth near the pipe and did not feel the heat at all. I said "That pipe, I guess, is cold," but on touching it was astonished at its high tempera-

ture. The temperature was evidently high enough to account for steam at pressure sufficient to run the engine. But if that pipe had been a non-lustrous black one the radiation from it would have been felt quite a distance away in passing the pipe. I think this planished steel is probably a good surface to prevent radiation, and, if the heat is prevented from radiating by the condition of the surface itself, and being in contact with felt it can keep some portion of the heat in it, there will be heat enough supplied to this bright covering to raise the temperature quite high, especially in view of the fact that the heat cannot readily get away from the surface into the air.

Mr. Sweet.—Did the jacket do harm or good?

Professor Robinson.—The asbestos covering does good, notwithstanding the bright outside sheet metal.

Mr. Sweet.—But the outside steel—is it any worse or better for having the planished steel on?

Professor Robinson.—It helps it. It has the advantage of covering the piece with a bright non-radiating surface, which will hold the heat back. The brighter the outside plate the better the asbestos covering and the less the heat escaping; all due to the non-radiation of the outside polished plate.

Mr. Spencer Otis.—Non-conducting lagging is used quite largely in covering locomotives, and the jackets which envelop it are planished iron. Last winter I was at Denver, and the superintendent of machinery of one of the roads took me out to the roundhouse and showed me an engine which had just come in from the mountains. It was lagged with magnesia and had a planished jacket. It was covered with snow, and enough heat had not come through the lagging to melt it down. The engineer who was running this engine said that it not only frequently occurred with his engine, but with other engines. So that it seems to me there must be some other reason for the sensible heat. I have since then on several occasions put my hand on the jacket of an engine so lagged, and unless there was a leak at some point, you could lay your cheek down on it and keep it there. But if there is a leak it will burn you. These engines carry 160 to 200 pounds of steam. Not long ago in St. Jo I had an illustration of the effect of leakage. I put my hand on the jacket and, in running over it, I came near the air pump. It appears the exhaust from the pump got up under the jacket, and I burned my hand in short order. The lagging is absolutely worthless

apparently if it gets wet. It occurs to me the insulating material may have been damp in the case of which Mr. Sweet speaks.

The President.—How thick was the lagging on this engine?

Mr. Otis.—The lagging on that engine in Denver was an inch and a half. I think their custom there is to use a minimum of an inch and a quarter.

Professor Robinson.—It would seem that my statement is of small effect, referring to the case of snow resting on pipe. But this is different from the case Professor Sweet refers to, notwithstanding only a certain amount of heat could come through this covering to the sheet metal, because one is a case of transfer by radiation and the other by direct contact. If the condition of the outside surface of the metal is such that the heat cannot get away from it readily, it becomes heated. If you apply a ball of snow against that plate it will take that heat away very quickly, by reason of contact and not radiation, and further heat will come to the metal plate and thence to the ball of snow only as fast as that resisting cover will permit the heat to pass. The case of snow resting on the pipe, to prove that my statement with regard to it was without effect, is, I think, proven by that way of putting it—that a ball of snow or the snow resting on the pipe can only get the heat that comes through the coating inside the plate, and hence the snow does not melt rapidly because of the non-conducting coating. I think the plate has no power in itself to supply heat to the snowball or snow deposit. It only gets its heat from the source within and through this coating and, as a matter of course, I think the condition of surface is one of small importance as to the rate of melting of snow that is in contact with it, because the heat is then transferred by contact; while when that sheet stands out free from contact, then I think the polished sheet would serve the purpose of withholding the heat by reason of the low radiating power of the polished surface and aid the coating between it and the pipe to hold back the heat, notwithstanding it is a metal plate, but just because it has a polished plate.

Prof. Thomas H. Gray.—I should like to say a word in confirmation of the point to which Professor Carpenter has drawn attention—the very great importance, in experiments of this kind, of taking care that the medium through which the heat is supplied to the pipe does not itself give an insulating film. The heat gradient from the oil to the metal pipe is likely to be very con-

siderable for a thin layer between the hot oil and the pipe. It is a matter of common experience in physical experiments on subjects of this kind to find that very rapid circulation is necessary to remove that film. We have great difficulty in removing the cold film from the metal. The same thing applies in the case of gas circulation, such, for instance, as we have in the hot flues of a boiler. The film of hot gases close to the flue is very much cooler than the average temperature of the interior. The consequence is that we have to reckon not so much with a very hot medium close to the pipe; then conduction through the pipe with almost infinite rapidity, you may say, but we have to reckon with conduction across a film of gas which lies between the hot gas and the pipe, and then conduction through the walls of the pipe. The same thing applies here in the case of the oil. There is no doubt, I think, that the actual numbers for the amount of heat conducted through will be greatly modified if the medium be modified. The comparative numbers, however, are probably in the proper order of magnitude.

With regard to the point brought up by the last two or three speakers, namely, the apparent discrepancy between the results obtained with metal covering on the outside of the insulating material and no metal covering, there is no doubt at all that when we depend upon radiation from a smooth surface we have very much slower emission of heat than when we depend upon a rough surface of the ordinary insulating material. The consequence is that the metal surface rises very rapidly to near the temperature of the inside pipe. The conductivity of the material is very much greater than the emission coefficient. The consequence is that heat is supplied through the conducting material at a rate which is very large in comparison with the rate at which the heat is taken off.

Coming to the next point which has been brought up, namely, the question of the effect of snow, we have to remember that if we are carrying a steam pipe through an atmosphere which is below the freezing point of water, we deposit snow or ice on the pipe and we get ice below freezing. Now, ice below freezing is almost a perfect insulator for heat—about as good as anything we can put on. The consequence is that unless we have a good conductor between the pipe and the ice we are not able to supply heat enough to melt any of the cold ice on the outer surface, because heat does not get through it fast enough to overcome the

chilling action of the atmosphere. The question of radiation or conduction in this case from the surface to the ice is of comparatively little importance. I think the results there described are just exactly what one ought to expect under the circumstances.

Prof. F. R. Hutton.—I think an interesting confirmation of the point raised by Professor Gray will occur to every one who has had any experience in boat-sailing with keel condensers. In starting the engine with the boat at rest the gauge needle will remain at a rather low point of vacuum; but the moment that the boat is moving through the water, the needle goes right down with the increased efficiency of condensation due to the circulation and the renewal of the warm films.

Mr. H. H. Suplee.—This question of the poor conductivity of ice, I think, is somewhat borne out by the use of a wet bulb thermometer in hygrometric measurements. When the temperature of the air is below the freezing point the great difficulty lies in the formation of a thin film of ice on the wet bulb, after which it is almost impossible to get its temperature to fall, although the temperature of the air may be very much lower. It is almost always necessary to resort to the use of some other form of hygrometer unless you can get the temperature of the wet bulb down so quickly that the film of ice has no time to form; showing that ice is a poor conductor of heat and will not allow the heat to escape from the bulb as rapidly as it otherwise would.

I think in connection with this discussion we might add snow to our list of non-conducting materials and sell it at commercial price.

Mr. Albert H. Bates.—It seems to me that this matter of the hot planished covering can be easily explained by the analogies of electricity. There we are familiar with static charges on surfaces. I think it is similar here. If this planished covering of the separator is insulated by the asbestos packing on the inside, we get a static charge of heat on that outside covering. Even though the insulating material allows very little heat to get through, still the little that does get through will gradually run up on the outside covering. But if there is any conductor to take it off from the outside covering it will not accumulate. In the case of the locomotive cylinder that conductor might be snow or cold air on the outside covering, or a direct conductor

with the cylinder head. But, it seems to me, in the case of the separator, that though the planished covering were insulated from the inside of the separator, some heat would get through, and this would gradually accumulate on the planished covering in what may be called a static charge of heat.

Mr. C. W. Baker.—While it is true that a bright surface radiheat less rapidly than a dull surface, it must be remembered that a hot body, such as a steam pipe, loses heat also by the direct contact of the air with it, by convection, as it is called. The amount of heat lost in this way, at ordinary steam temperature, is probably considerably greater than the amount of heat lost by radiation. As the loss by convection is affected very slightly, if at all, by the character of the pipe surface, it will be seen that the influence of a bright surface, such as planished iron, in preventing loss of heat is hardly so great as some of the speakers have claimed.

The author of the paper under discussion has in fact made experiments upon this very point, the results of which are recorded in Table 7. It is there shown that the comparative loss when the pipe was painted a dull black and when it was painted a glossy black was as 14 to 12. The correct conclusion seems to be that planished iron jackets for locomotive boilers, bright tin for hot-air pipes, etc., do cause some small reduction in the loss of heat, but their influence is as a rule unimportant compared with the reduction in heat loss which is effected by a layer of good non-conducting material.

*Mr. C. L. Norton.**—Professor Carpenter's criticism of the method does not seem to me justified. The conditions of the test are identical with those of actual practice. If a pipe is kept at a temperature of 350 degrees Fahr. and the surroundings are at 70 degrees Fahr. the pipes will lose a certain definite amount of heat, no matter how the pipe is kept hot. This requires no further demonstration, being a well-established law. Now, by actual experiment I have found what the temperature of a pipe carrying steam at varying pressure is, and have made my tests accordingly. I do not see that Professor Carpenter's experiments have any direct bearing on the matter in hand.

I have made some condensation tests on a long run of large pipe at 100 pounds, and I find my results with the small oil

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*Author's Closure, under the Rules.

tester very closely borne out. I do not believe the absolute figures in the tables can be more than 5 per cent. from the values actually found in practice.

The effects of air currents and the increase in the moisture of the air have been studied, and I have been unable, by means of electric fans and artificial dampening of the air, to change the heat loss from a pipe enclosed with a cover by more than ten per cent.

Mr. Meyer's remarks as to the durability of a cover touches on a very important point and one which must some time be more carefully discussed. The only information at hand concerning this point is that nonpareil cork, magnesia, and oil cell cords which I tested in 1895 are as good as new to-day, although they have been most of the time since July, 1895, on a pipe at 100 pounds pressure.

Further, I have tested a section of K. and M. magnesia six years old, and I find it identical with some bought in the open market last month.

DCCLXXXIII.*

METHOD OF MANUFACTURE AND TESTS OF A NEW SEAMLESS TUBE.

BY R. C. CARPENTER, ITHACA, N.Y., AND P. J. FICKINGER, BEAVER FALLS, PENN.

(Members of the Society.)

DURING the past few years the manufacture of seamless tubing has grown to be an important industry, due principally to the demand which has arisen in the process of manufacturing bicycles.

The seamless tubing to be described in the following paper is made by a process of drawing from a superior quality of steel pipe; † it is seamless in the sense that no indication of the weld which existed in the original stock before drawing is visible in the drawn product, nor could its position be ascertained by any of the numerous tests which were used to rupture the finished tubing. The tubes were tested by twisting in a torsion machine, by compression, by tension, by transverse loading, and by bursting, and in no case did rupture take place in such a manner as to even indicate the existence of a weld in the original stock.

The methods which are extensively employed in the manufacture of steel tubes for use in bicycles are as follows:

First, the seamed tube which is made by rolling up a strip of metal of proper dimensions until the edges come in contact and then welding or brazing the edges; such tubes are all characterized by a longitudinal seam which is apparent even to a casual observer, and have proved less satisfactory and weaker than the forms of seamless tubes to be described; they are at the present time not in extensive use.

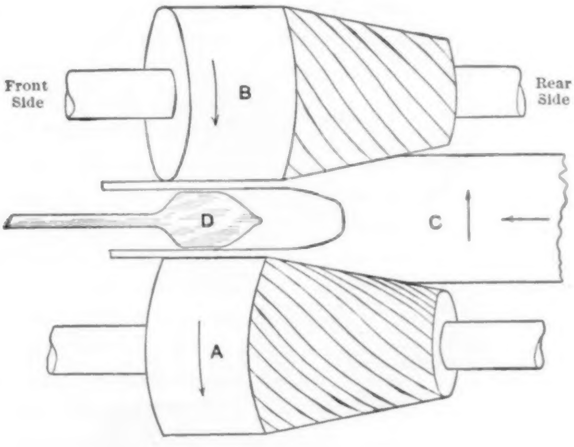
Second, the Mannesmann tube, which is formed by a process

* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

† Analysis of steel employed is claimed to be as follows: carbon 0.08 to 0.10, manganese 0.45, phosphorus under 0.04, sulphur 0.04 to 0.05, silicon 0.009.

of rolling between two rolls, the axes of which are set obliquely to the axis of the billet. This process has been extensively described, and is generally familiar to those who have studied the subject of manufacture of tubing; but a few words regarding the process will be given here.

In Fig. 175 is shown a diagram of the rolls *A B*, turning on axes oblique to each other and acting on the billet *C*. The rolls revolve in the same direction at equal rates of speed and have their rear edges conical in shape and covered with helical grooves. The action of the rolls is to extend the



MANNESMANN PROCESS.

Fig. 175

outer fibres of the billet, opening the mass and forming a cavity situated in the centre; the cavity begins with the form of an egg-shaped cup, and gradually works itself outward until the other end of the billet is reached and pierced. A conical mandrel is often employed, as shown at *D*, its purpose being to further obstruct the motion of the inner particles to secure a perfectly circular section and to polish the interior of the tube; it is apparent, however, from the action of the rolls in expanding the outer fibres, that a cavity would be formed, even were no mandrel employed, and furthermore it is quite possible to form, by the Mannesmann process, tubes with closed ends. After the billet has been pierced and partially worked

into a tube by the Mannesmann process, the tube is completed by the ordinary process of drawing.

The Steifel process is a modification of the Mannesmann process, and is used to considerable extent in the manufacture of seamless tubes. In this process the exterior portion of the billet is rolled between two conical discs revolving on parallel shafts in such a manner as not to subject the billets or blanks to a torsional strain nor to one which will disturb materially the longitudinal arrangement of the fibres of the metal. The billet is forced against a conical piercing mandrel as it passes between

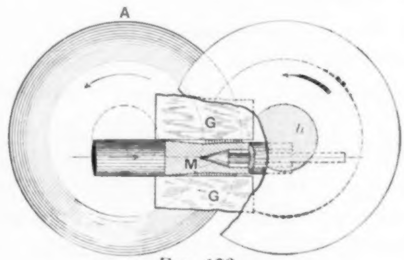


FIG. 176.

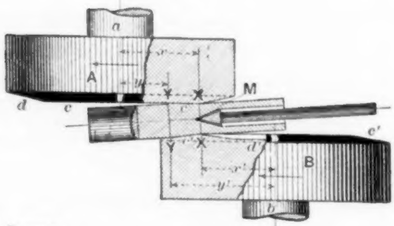


FIG. 177.

the working surfaces of the discs, it being arranged so that the mandrel may be rotated or fixed as desired. A plan view of the operating mechanism is shown in Fig. 176, and a side elevation in Fig. 177, the action of the various parts being as follows:

The discs A B lie in parallel planes, and are mounted on the ends of the shafts a b, the axial lines of which are also parallel, and lie in the same horizontal plane. These shafts may be mounted in any suitable housings, and motion is imparted to them by any suitable gearing or driving mechanism. The working portion of the face of each disc is near its periphery, and as the shafts are not in the same axial line the right hand side of one disc is opposed to the left-hand side of the other. The

discs revolve in the same direction as indicated by the arrows thereon, so that a blank or billet passed between them in contact with their opposing surfaces has imparted to it a rotary movement; and if the blank is passed between the discs, either slightly above or below the plane of their axes, it has imparted to it a longitudinal movement also.

In Fig. 176 the working faces of the discs are formed by a part of the plane surface c of the disc A, and a part of the outer bevelled surface c' of the disc B, the outer diameter of the surface c being the same as the inner diameter of the bevelled surface c'. The edges formed by these two surface diameters lie opposite each other at the pass for the blanks, so that the pass is narrowest at this point, as indicated at the line XX. The axial line of the pass is located below the centres of the rolls, as shown in Fig. 177, and guide-blocks G of suitable construction are employed to hold the blanks in proper position. The blank enters the pass at its widest point near the line YY, where it is gripped by the rolls, revolved, and gradually forced forward into and through the narrowest part of the pass at XX, upon the point of the conical mandrel M, and from thence over the remainder of the mandrel, but out of the grip of the discs.

The disposition and shape of the discs are such that their action upon the blank elongates or draws it out without imparting any spiral twist to the fibre, resulting in a finished pierced blank, the fibres of which are parallel to each other and substantially straight, or without twist, and this feature constitutes the main aim and object of the invention, and forms the principal distinction from the Mannesmann process. This result is accomplished by imparting to the blank a substantially uniform speed of rotation throughout all those portions of it in the grip of the working surfaces of the discs. At the point XX, where the pass is most contracted, and the grip of the discs on the blank the greatest, the radii xx' of the two discs are the same, and consequently the speed of rotation imparted to the blank at this point by both discs is the same. At the line YY in the pass, while the radius y of one disc is smaller than the common radii xx' of both discs, the opposing radius y' of the other disc is proportionately greater than the common radii xx', so that the mean effective rotative action imparted to the blank by the two discs at the line YY is the same as that imparted to it at the line XX; or, to express it another way,

the circumferential speed of the disc A is slower at its radius y than at its radius x, and consequently its rotative action on the blank is slower at Y than it is at X, but the circumferential speed of the other disc B at its opposing radius y' is as much greater than at x' as y is slower than x, so that the mean effective rotative action upon the blank of the smaller and larger radii yy' of the two discs, respectively, is the same as that of the common radii xx'. Consequently that portion of the blank lying within the grip of the discs at the line YY is rotated at substantially the same speed as that portion at the line XX. As this condition prevails in every point in the grips of the discs between the lines XX and YY, a larger radius and greater circumferential speed of one disc being opposed by a smaller radius and slower circumferential speed of the other, there is practically no twisting of the blank within the grip of the discs by reason of one portion of the blank being rotated faster than another portion. There might, if there were no slippage, be a slight difference of speed of rotation of portions of the blank within the grip of the rolls, due to the fact that the diameter of the blank is slightly smaller at XX than it is at YY, but owing to the slippage this does not occur, and the blanks, when they leave the pass between the discs, have their fibres substantially straight and parallel throughout. This reduction of the diameter of the blank between the lines YY and XX is not intended particularly for its effect in compacting, working, or drawing out of the metal, but is the result or consequence of the contraction in the width of the pass necessary to give the discs sufficient grip or hold upon the blank to force it forward upon and overcome the resistance of the piercing mandrel.

For both the Mannesmann and Steifel processes steel of superior quality and entirely free from flaws must be employed, since the action of the process is such as to tear apart any particles or fibres which were not perfectly welded in the original billet; the process itself rejects a bad grade of material by making imperfections apparent to the eye.

Third, a process of spinning from a sheet into a cup-shaped piece, from which, by cutting off the closed end, a hollow tube is produced which is reduced by drawing to the required size and diameter.

Fourth, a process by means of which a tube may be drawn

from the solid billet of steel after a hole has been pierced through the billet. The principal difficulty with this process is that of piercing a hole through the centre of the billet, which is done when in a semiplastic state. For this purpose billets are used about 14 inches in length and 4 inches in diameter; these, after being pierced, are converted into tubes by rolling over a mandrel of the requisite diameter preparatory to cold drawing.

The seamless tube which forms the subject of the article is made by a process of drawing from welded steel pipe. The novelty of the process lies entirely in the machinery employed in drawing and in cleaning the tubes from the oxide of iron before and after the drawing process. All other processes of producing tubing require the use of high-grade steel in order to produce tubing of reliable quality and with strength sufficient to meet the requirements of use. Swedish billets are imported for most of the steel tubing, which, for the last few months, have,

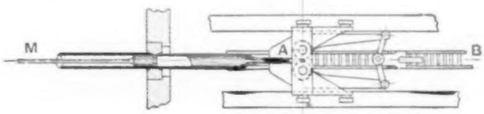


FIG. 180.

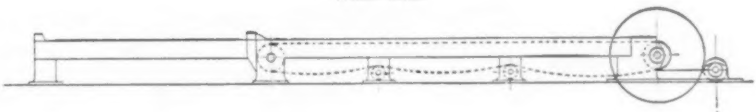


FIG. 179.

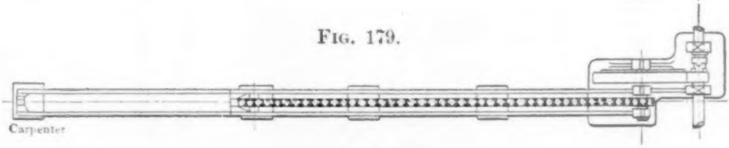
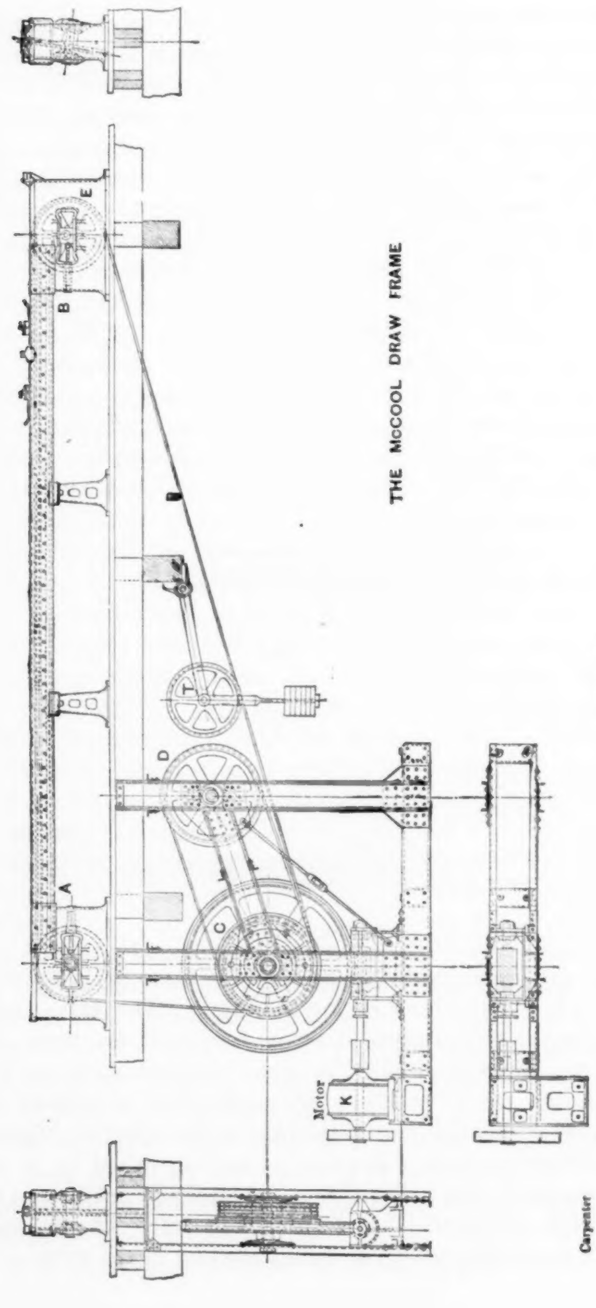


FIG. 178.

strange to say, been quoted at exactly the same price for which the finished tubing is sold for at retail. The tubes manufactured by the new process show, as results of the tests made, equal if not superior quality in every respect to those made from imported stock, yet they are made from American steel costing from one-half to one-third that of the Swedish billets.

The ordinary process of drawing is accomplished in a draw frame as shown in plan in Fig. 178, in elevation in Fig. 179, and with enlarged view of drawhead and die in Fig. 180. The process of drawing is accomplished by reducing the end of the tube so that

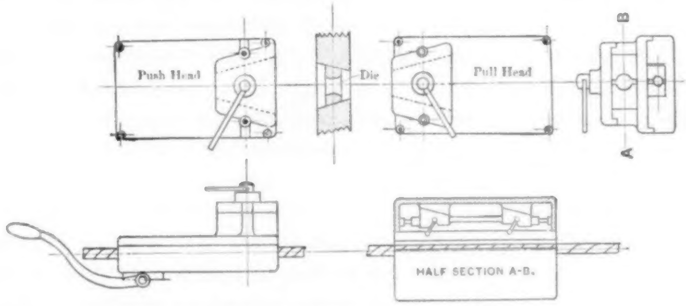


THE McCOOL DRAW FRAME

Fig. 181.

Carpenter

it will pass through the die and can be grasped by the pulling drawhead as shown at *A*, Fig. 180. The drawhead is made to engage with a travelling chain *B*, and thus pulls the tube through the die and over the conical mandrel shown at *M*, Fig. 180. The principal novelty of the machine employed by the

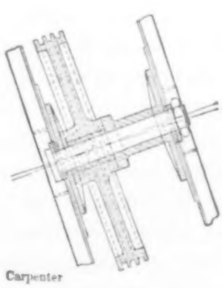


Carpenter

PLAN AND ELEVATION OF DRAW HEADS

FIG. 182.

Tube Company in the improved drawing process consists in the use of a pushing as well as pulling drawhead, of a peculiarly shaped die, and of the method of applying power to move the drawheads. A complete drawing of the machine is shown in side elevation in Fig. 181 and in end elevation in Fig. 182. The drawheads are shown in plan and elevation in Fig. 183, and



Carpenter

FIG. 183.

consist of both a push and a pull head, one of which is located on either side of the die, and each of which carries a chuck for clasping the pipe and a grip by means of which it can be attached to or detached from the rope used for moving the drawheads. The pushing drawhead is used only to crowd

the tube through the die. It is attached to the tube about one foot from the free end of the tube and in such a manner as not to interfere in any way with the free motion of the particles of the pipe due to the increase in length in the drawing process. After the tube is passed through the die it is caught by the pulling drawhead which is located on the other side of the die, and is then drawn in the usual manner through the die; simultaneously with the attachment of the pulling drawhead the pushing drawhead is released. The construction of the pushing drawhead was only accomplished as a result of numerous experiments, and it was believed generally by those familiar with the process of drawing that the operation of pushing the tube into the die was impossible. The use of the pushing die saves all work of preparation of the ends of the pipe to make them enter the die and all waste due to the production of bad and ragged ends on the drawn tube. In the drawing machine the drawheads are moved by being attached to a rope by means of a grip instead of being pulled, as in the ordinary process, by a chain. Considerable experimenting was required in order to produce a satisfactory drawing machine. The form of the machine which is in use is shown in drawing Fig. 178, from which it will be noted that the rope *R* for the draw passes beneath the draw frame *AB* and is made to take three wraps around two grooved pulleys *C* and *D*, thence over an inclined idler *E*, which returns the rope to the central position of the frame; the slack of the rope is taken up by a tightner pulley *T*, of the usual construction. The machinery of each drawing frame is operated by a 15 horse-power induction motor *K*, which is connected by spur and screw gearing to the driving pulley of the rope drive. The starting bar for the motor is in convenient reach of the operator, and is connected so that the motor can be run in either direction as required. Ropes $1\frac{1}{4}$ inches in diameter are employed, and have been found to have a reasonable life, the cost of repairs being less than when chains are used for a similar purpose. The practical advantage which the rope has been found to possess over the chain for drawing purposes is due to its elasticity and stretch, by means of which the tube is drawn gradually through the die, and there is an entire absence of jerky motion, which is so destructive to tubes when the drawing is performed by chains or other rigid material. The improvement on the character of the stock due to the yielding nature

of the pulling mechanism is decidedly marked. The drawhead clutch is arranged with a safety opening device, so that the clutch would be released if by any means the drawheads were carried beyond the limit of safe travel.

The method of cleaning the scale from the tube is found to have an important influence on the quality of the tubing, and has been one of the most difficult problems to solve successfully. The use of the ordinary open bath with 8 to 10 per cent. acid was found to injure the tubing materially, and after extensive experiments a more satisfactory process of cleaning was discovered, in which the use of less than 2 per cent. acid is found to clean successfully a rack of tubes in a length of time not exceeding 15 minutes. These good results are due to the fact that the tubes are immersed in a vertical position with both ends open and in such a manner as to allow a free and uninterrupted circulation of the liquid of the bath.

In the practical operation of the plant the tubes to be drawn are passed in succession and at a rate of 24 feet per minute through the different dies until they have reached the required diameter and gauge, being annealed and cleaned after making each pass. During the operation of drawing, whenever the length of the drawn tube exceeds from 18 to 20 feet, it is immediately cut into lengths of 9 to 10 feet, and the process of drawing continued. At present the original tube before the drawing begins, which is employed for bicycle tubing, is 1¾ inches external diameter.

A general view of the drawing-room is shown in Fig. 184, from which it will be noticed that there is an entire absence of overhead shafting or of moving machinery of any kind, except that connected to the draw benches. An observer would also be struck with the cleanliness of the room and of the dress of the workmen and of the entire absence of grease or oil on the floor. This latter result is obtained by immersing the tubes, before each process of drawing, in a hot bath of greasy material, which, when cooled to the ordinary working temperature, has the consistency of wax or varnish, which adheres to the tubing in a very thin coat, and, although sufficient to lubricate the dies, is insufficient to fly off and cover the floor and working machinery with layers of grease.

The annealing is done in a natural gas furnace, the tubes being moved by automatic machinery at a rate just sufficient to

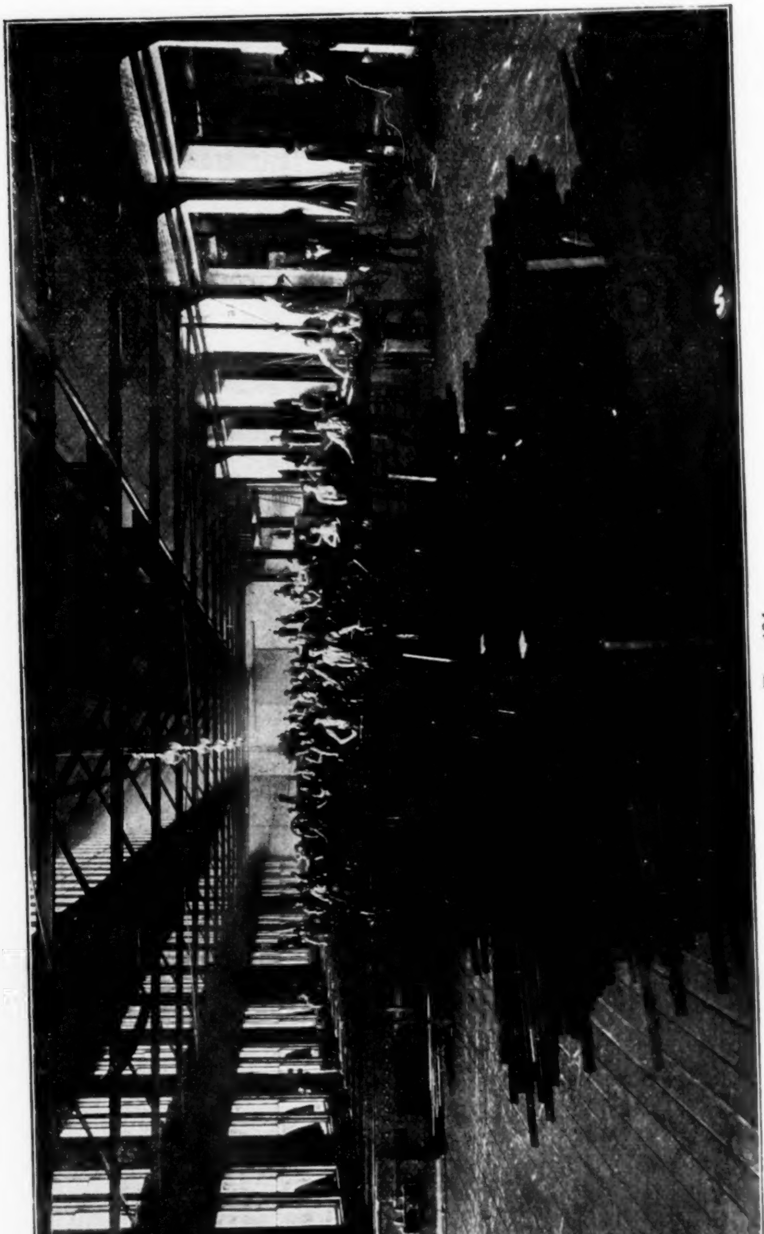


Fig. 184.

anneal the tubes with one passage through the furnace. The unannealed tubes, while harder then the annealed, were found, as will be shown by the tests later, to have considerable elasticity and to be of quite uniform quality.

The building is a model workshop of its kind, and was designed by P. J. Fickinger.

It is provided with both side and roof lights, the roof windows being arranged in such a manner that the sashes are vertical and the light enters from the north, thus giving the shop light without any of the glare of direct sunlight, and rendering the use of shades unnecessary.

Tests of the Drawn Tubing.

Tests of a number of samples of the McCool tubes were made in the laboratory of Sibley College, Cornell University. The

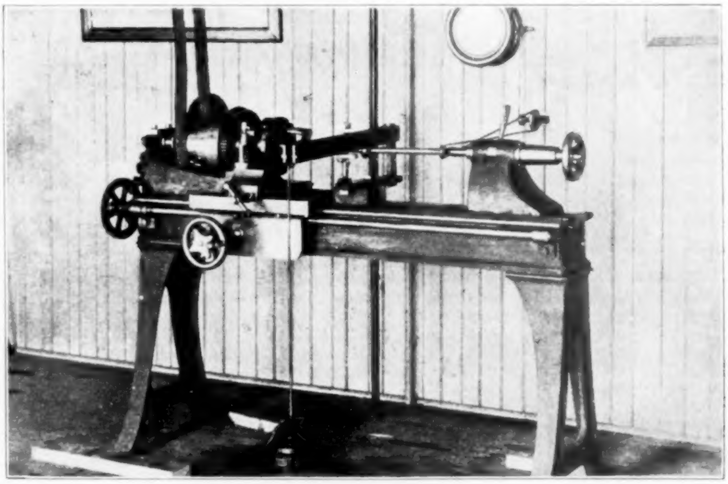


FIG. 185.

tests undertaken were such as would bring out the weakness, if any existed, due to the use of the welded joint in the original stock.

Transverse Tests.—Test No. 2, gauge 18, annealed, external diameter 0.875 inch, internal diameter 0.785, was carried on supports 18 inches apart; it supported a centre load at elastic limit 340 pounds, at yield point of 370 pounds, and at maximum

FIRST.—TENSILE STRENGTH.

Character of Tube.	External Diameter.	Internal Diameter.	Load per Square Inch.		Reduction Area.	Elongation.
	Inches.	Inches.	Elastic Limit.	Maximum.	Per Cent.	Per Cent.
No. 90. Original.......	1.176	1.472	36,700	60,000	52	....
No. 7. Annealed......	1.002	0.880	41,700	64,400	36	20
No. 3. Annealed......	0.749	0.692	70,200	91,600	14	....
No. 1. Unannealed....	0.752	0.688	93,100	94,700	12	....

SECOND.—TESTS OF THE TUBES IN TORSION.

	Diameter.		Moment of Torsion Inch, Lbs.		Shearing Stress per Square Inch.		Modulus of Rigidity.
	External.	Internal.	Elastic Limit.	Maximum.	Elastic Limit.	Maximum.	
No. 4. Unannealed..	0.874	0.778	1,900	2,870	39,600	60,000	10,800,000
No. 60. Annealed ...	1.248	1.184	2,800	3,200	37,000	42,000	11,500,000
No. 5. Annealed ...	1.00	0.880	2,800	3,100	32,500	38,800	11,400,000

Rupture of No. 60 began at a slight dent in the tube.

Tube No. 7, extension was measured for 8 inches in length and was equal to 1.1 inches. Maximum load sustained 11,600 pounds.

strength of 380 pounds, the latter load corresponding to a calculated fibre stress of 72,200 pounds per square inch.

Endurance Tests.—A number of tests were conducted by mounting the tube so it would be supported between the centres of a lathe, in such a manner as to be free to deflect and yet could be rotated at any desired rate of speed. A bushing or washer was carried by the tube at the centre, and this was fixed so as to rotate with the tube and support a load resting on rollers. The method of arranging for this test is shown in Fig. 185. Especial care has to be exercised that the rollers freely revolve and that the bushing does not turn on the tube. The centre load was selected so as to produce a fibre stress equal to 60 to 90 per cent. of that at the elastic limit of

the tubing. By consulting the table it will be noted that the loads taken were such as to produce stress respectively of 58,000, 50,000, and 40,000 pounds per square inch in the outer fibre. The number of revolutions made by the tube when loaded in that manner was denoted by a continuous counter, connected so that it would not register after rupture took place. The number of reversions of loading would equal twice the number of revolutions. The following table gives the results of this test:

No. of Test.	Name of Tube or Maker.	Diameter Inches.			Centre Load. Lbs.	Stress in Outer Fibre. Lbs. per Sq. In.	Deflection at Centre. In.	Revolutions.	
		Inside.	Outside.	Length.				Per Min.	Total.
R. 1	McCool, annealed..	0.691	0.749	21	128	59600	0.24	44 to 230	39638
R. 2	" unannealed	0.687	0.751	21	128.5	54500	0.20	230	79826
R. 4	" "	0.789	0.873	21	240.5	58000	0.17	300	77098
R. 5	" "	0.750	0.686	21	113	50000	0.175	300 to 400	211232
R. 7	Unannealed	1.069	1.125	21.7	280	58000	0.15	300 to 400	14752
R. 8	"	1.069	1.125	21.7	242	50000	0.10	300 to 400	92230
R. 9	Annealed..........	1.068	1.125	21.7	242	50000	0.10	300 to 400	20534
R. 11	"	1.186	1.250	21.7	348	50000	0.10	....	25942
R. 12	Unannealed	0.780	0.875	21.7	179	40000	......	....	82154
M...	Annealed..........	0.810	0.884	21	218.5	57600	0.13	230	13214
N...	"	0.803	0.875	21	212	58000	.19	230	25036
P...	" in oil....	0.791	0.875	21.7	168	40000	0.12	300 to 400	46498

Remarks:
R. 1. Stood under load over night.
P. Flew out of lathe and across the room when it broke.
R. 7. The first deflection was 0.10. The tube vibrated until about 4,000 revolutions, when it became steady, and the deflection was 0.15.
R. 11. Centre load of 350 pounds makes a decided set.
R. 12. This load is about $\frac{2}{3}$ that of elastic limit.
M. Tube made by Mannesmann process.
N. Tube made by punching original ingot and drawing.
P. Tube made by spinning and drawing process.

The general appearance of the fractured specimens is shown in Fig. 186, those marked 4, 5, 8, and 40 respectively being broken in torsion, those marked 7 and 90 being broken in tension, and the remainder in the endurance tests.

Bursting Test.

Several bursting tests of tubes were made by clamping the tube endwise between two metallic heads, one of which was perforated and connected by small tubing to a pressure pump. After applying pressure of about 5,000 pounds per square inch the tubes in most cases were deflected from a vertical line and the test had to be discontinued. In order to successfully continue

the bursting test, a support or brace was placed at the centre of the tube, and the tube was also reduced in length from 30 to 10 inches.

The tube which bursted had an external diameter of 1.254

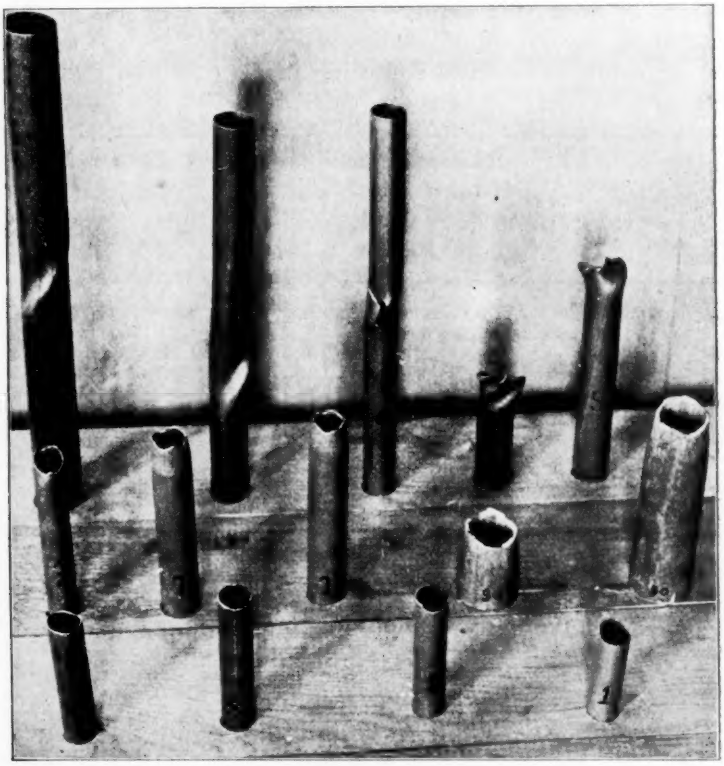


FIG. 186.

inches, and an internal diameter of 1.202 inches, a thickness of 0.026 inch, corresponding to a gauge of between 22 and 23. The tube burst about 3 inches from the top with an internal pressure of 4,700 pounds to the square inch, which corresponded to a tearing stress per square inch of 108,642 pounds. It did not burst in a weld. The external diameter was increased about one-sixteenth of an inch, by the internal pressure; a view of the tubing is shown in Fig. 187.

The results of the previous experiments referred to indicated

that a tearing stress, equivalent to 80,000 pounds per square inch, could be applied without rupturing the metal. Mr. Fickinger in a previous test applied a tearing stress equal to 70,000

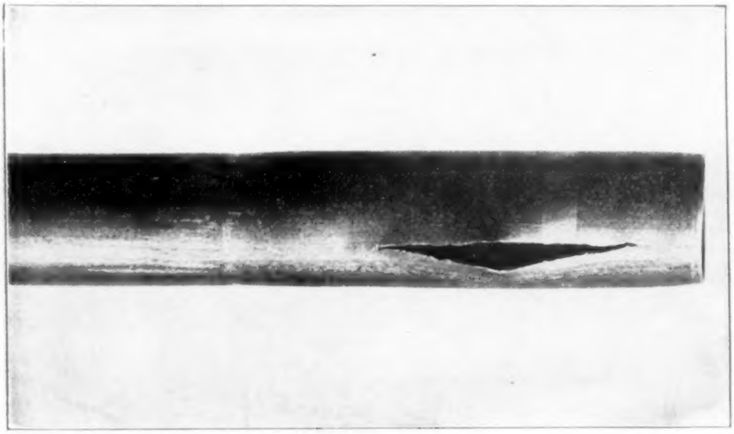


FIG. 187.

pounds per square inch without sensibly increasing the diameter of the tube.

FIG. 188.

Crushing Strength.

Several specimens were tested by crushing in the testing machine. The tendency of most of the pieces, when failing in compression, was to make a succession of folds forming regular

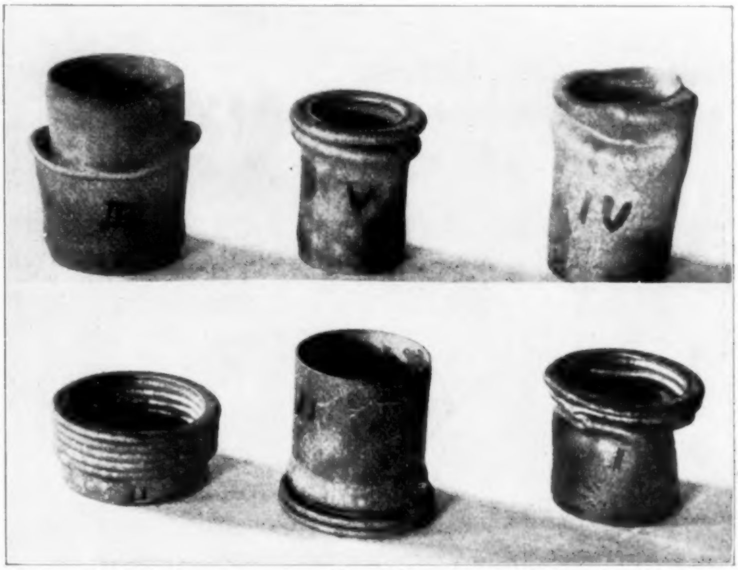


FIG. 189.

rings, as illustrated in Fig. 188. These rings were formed without splitting or tearing of the metal in any way.

The general results of the various crushing tests are given in the appended table, and the appearance of the specimens after being crushed is shown in Figs. 188 and 189.

RESULTS OF CRUSHING TESTS.

No.	External Diameter. Inches.	Thickness. Inches.	Approximate Gauge.	Length. Inches.	Crushing Load. Pounds.	Remarks.
0	1.75	0.026	23	$1\frac{15}{16}$	7,600	Shown in Fig 14.
1	1.125	0.029	22	2	5,000	" " 15.
2	1.25	0.028	22	2	5,000	" " "
3	1.125	0.035	20	2	6,000	" " "
4	1.0	0.042	19	2	7,000	" " "
5	0.875	0.048	18	2	8,000	" " "
6	1.125	0.028	22	2	5,000	" " "

The specific gravity of a number of the tubes was taken, and the results are given in the following table. It will be noted that the variation in specific gravity is very small, but that in general the annealed are slightly heavier than the unannealed.

SPECIFIC GRAVITY TESTS, MAY 3, 1898.

Name of Tube.	Dimension.			Weight.—Pounds.			Specific Gravity.
	Diameter.	Thickness.	Gauge.	In Air.	In Water.	Difference.	
McCool (M—1), annealed....	1.25	0.026	23	0.1110	0.09685	0.01415	7 83
" (M—2), annealed....	0.875	0.0475	18	0.15558	0.13571	0.01987	7.83
" (M—3), unannealed..	0.750	0.034	21	0.09057	0.07890	0.01167	7.76
Tube M....................	0.884	0.037	20	0.13224	0.11523	0.01701	7.77
Tube N....................	0.875	0.036	20	0.1154	0.10073	0.01477	7.81
Pope A, annealed...........	0.875	0.042	19	0.12162	0.10610	0.01552	7.83
Pope B, oil tempered........	0.875	0.033	21	0.11035	0.09618	0.01417	7.78
Original tube, McCool process	1.75	0.143	..	0.28265	0.2465	0.03643	7.83

DISCUSSION.

Prof. R. C. Carpenter.—I would like to add in regard to the method of making the endurance test, what I should have stated in the paper, viz.: that the apparatus which was used for making this test was modelled closely—and finally, before using it, was copied almost exactly—from the drawings of the machine used at the Watertown Arsenal for this purpose. It is not a particularly excellent design. I think Mr. Henning can help us out very much by describing better methods of performing this.

In regard to the compression test, there were some results which seemed to me very remarkable, since in my previous experiments I had never obtained such results in crushing pieces of the tubes which were cut from the annealed tubes at random—this was originally $1\frac{3}{4}$ or $1\frac{7}{8}$ inches in length—I cannot tell exactly without looking it up—and simply pressed between the two heads of the machine and crushed down, and there was a tendency for practically all of the pieces to curl up into this form. Some of them crushed a few inches and moved off on one side. That was no doubt due to the imperfection of the machine in which the operation was performed.

Mr. Henry Souther.—The description of the McCool process of making tubing is especially interesting, and notably so in connec-

tion with mechanical operations and features. It seems, however, to me that it is a mistake to call tubing made by this process seamless. It is admitted by the writers that the tubing originally is welded in precisely the same manner as ordinary gas pipe made by lap-welding or butt-welding.

Such tubing has quite as much right to be called seamless as it would after having been put through the McCool process, inasmuch as if the weld during hot-working was not absolutely perfect it would not be made so by anything which is done to it during the McCool operations.

I think that no competent metallurgist would claim that an imperfect weld would become perfect during any form of cold-working. It is a well-known fact that flaws in the seam develop during the testing of large quantities of ordinary welded pipe. It is quite possible that none of the specimens tested in connection with this paper showed any signs of a joint, and yet it is also quite possible that in testing and manufacturing large quantities quite as many flaws would develop as if the tubes had never been cold-drawn after welding.

It is evident that much depends upon the thoroughness of the weld in connection with the McCool process. High carbons do not weld as well as low carbons. It therefore seems as though what is becoming to be considered really strong steel, especially suitable for the resisting of vibratory strains, cannot be as safely used in connection with this process as it can in connection with various other processes described.

In regard to the quality of steel used, there seems to be a certain contradiction upon the first page of the paper and, again, later. The paper says "The seamless tubing to be described is made by a process of drawing from a superior quality of steel pipe." The analysis of the pipe given at the bottom of the page in a foot-note is very far from being of superior quality even for steel pipe. Again, on page 759, appears the following sentence: "All other processes of producing tubing require the use of high-grade steel in order to produce tubing of reliable quality and with strength sufficient to meet the requirements of use." This is certainly not true as stated. There are various processes for producing tubing of fair quality from comparatively poor stock. In fact, a great deal of tubing commonly used, when analyzed, is not one bit better than that shown by the analysis given in this paper, poor as it is, which is certainly a proof that the McCool process is not an abso-

lute necessity to allow of the use of inferior steel. The descriptions of the methods of producing seamless tubing are exceedingly lucid, and should be read by those unfamiliar with the tube business, as they give as clear an idea of the processes as any description I have had the good fortune to come across. There is little to be said about the first process mentioned, that of uniting the edges of a rolled-up strip by welding or brazing. All authentic tests of such tubing which have come to my notice have developed fractures at the joint in every case soon after passing the elastic limit.

This ought to be expected in the case of brazed tubing, inasmuch as the moduli of elasticity of brass and steel differ so greatly. The process is hardly more than a makeshift to produce, at the sacrifice of reliability, a low-cost, nicely finished tube.

The descriptions of the Mannesmann and Steifel processes are very clear and interesting. That these processes develop any flaws which existed in the original steel would be a recommendation, if it were a fact, but I very much doubt whether flaws are so detected. On the contrary, these methods are likely to weld and close any flaws or blow-holes that may have existed, inasmuch as the temperature of working is very high, and welding may take place during the first moments of the operation. Cold-working, however, whatever the preceding process, certainly does expose flaws and defects, and this is one of the advantages gained by the method. I have seen a considerable amount of tubing made by both of these processes which was not of the best material.

In the third process described, the expression "spinning from a sheet" is used. Spinning may be resorted to sometimes, but the first operation as actually practised is nearly always one of cupping by the direct thrust of a cup-shaped punch through a die, this being continued with smaller and smaller punches until the tube is long enough to have the end cut off.

In describing the fourth process the writers have neglected to mention that, in addition to piercing the billet hot, drilling is resorted to quite as often, and, in fact, is one of the favorite methods used in England, and has been for over fifty years.

The use of a pushing draw-head for entering the tube into the die is one that I would hardly have expected to prove successful, at least after the tube had become rather small in diameter and at the same time thin—for instance, for such sizes as are used for bicycle construction.

It is particularly unfortunate that pickling has to be resorted to, as the bad effect of the pickle referred to on page 763 of the paper is only too well known, and probably causes a greater deterioration in tubing than could be overcome by any method of manufacture. If it is avoided entirely the product is sure to be the better for it.

On page 763 the amount of acid in connection with pickling is mentioned as being very small, namely, 2 per cent. I would like to state in connection with this that less than 1 per cent. is now the common practice of most tube and wire drawers, and that the standing of the tubes on end and causing the water to be forced up through them at a very rapid rate has long been common practice for the purpose of hastening the action of the pickle.

The data given in connection with the tests are so indefinite, particularly as regards the condition in which the tubes were when tested, that intelligent discussion is not possible. The terms "annealed," "unannealed," "annealed in oil," and "original," which are used, furnish no information which would allow one to make a series of tests with the hope of getting another set of specimens into approximately the same condition for comparison.

For about four years we have been working in our laboratory upon the tests of material with the promoter and testing machine side by side. We have found without question that the term "annealed," as ordinarily used, that is, the relieving of internal strains, is about as indefinite a term as exists in connection with the testing of materials. We have demonstrated without a question that, by varying the temperature and time of anneal, the elastic limit of a given piece of steel may be varied from 30,000 to 60,000 pounds per square inch. We are also obtaining data which point toward the fact that a given steel annealed at its point of recalescence is in its very best condition for combined strength and toughness and refinement of grain.

In referring to unannealed specimens the writers of this paper undoubtedly mean tubes as taken from the draw-benches after cold-drawing. The degree of cold-drawing is not mentioned, and in fact it is extremely difficult to cold-draw two tubes not drawn through the same dies and reproduce a condition. From the results of some of the tensile tests, particularly specimen No. 1, it is evident that the tubing was exceedingly hard drawn.

The elastic limit of these cold-drawn specimens is given with a great deal of certainty as to its location; and I would like to say

that information as to just how this point of elastic limit is located with any exactitude would be of much value to me and, probably, many others who are testing cold-drawn material. It is my experience, with all the data obtainable, that the stress diagram of a tensile test is such a gradual and uniform curve from the beginning to the end that no one point can be found at which it can be certainly stated there is evidence of an elastic limit. The more severe the drawing, the more is this true. A mild-drawn specimen sometimes shows a yield point which can be located with a fair amount of certainty, but a hard-drawn specimen never does.

The term "annealed in oil" is extremely indefinite, no data being given as to the original quenching temperature or the temperature of the oil in which the specimen was annealed.

As a matter of fact, I think that the Society should not accept records of tests of which the full data are not given, especially as to the condition of the specimen tested. Without the fullest of data in this respect, the results of the tests are of little use.

Mr. Gus. C. Henning.—I would merely like to call attention to the tests which were made, because they illustrate a principle very beautifully, and I think that those tests would have been still more beautiful if the machine used for producing them had been more perfect itself, because it depends mainly on the action of the machine. If a column of ductile material or even of cast iron be placed between two heads and vertical pressure applied, the first change of shape will be a single bend; the second will be the reverse, and then suddenly in an infinitely small space of time you will see the column change into the S-shape. It goes like a flash from the one shape into the other. Ultimately the cast iron can be made to take a curve which has reverse curves at each end, provided the machine is rigid and the heads cannot move in either direction. Now, the short specimens did not allow much motion in the machine, of course, but these other tubes, that one especially, show it distinctly. Here are two rings formed very nicely, and a third ring began to form, and, where the folds are, the head is simply twisted a little bit to one side, and there was a transverse instead of a compression test. These folds occur one after another, as is well known, from mathematical reasons. Let us take these in series. The head held one end of the tube or the end, and these ends cannot change much, but between them is a weak point, and that first weak point generally occurs somewhere near one

support or the other, depending upon the perfect holding of the end. One end was held better than the other, and therefore the folds were more uniformly distributed over it, and the folding occurred, as shown. The other head which bore on the tube did not offer a good support. Therefore the uniformity was distributed on the lower head. The first thing that will happen will be to extend a little, just as is seen at the irregular part, and then immediately thereafter there will be flexure, and this irregularity will form. If the test had stopped, you would have had a fold probably something like that shown in the other samples. You can keep on testing as long as you keep the heads centrally over the axis, the material being uniform of course. You can increase these folds until you find a point in the tube where there is a defect; and this is actually used, as I am told, for testing tubes, even heavy tubes, in Berlin, where Professor Martens, with his carefully adjusted machines, uses the number of folds and the time of folds in regard to the evaluation of the uniformity of the material in the tubes. Of course this material shows the behavior of it. Under these conditions it shows that it is wonderfully uniform, and I think that is really remarkable. It shows that the weld is entirely obliterated by the subsequent work, and that it is not a defect in any sense, and, judging from the samples, if the same care were devoted, larger tubes could be made with the same satisfactory results.

Mr. C. W. Baker.—In the description of the Steifel process given in this paper the impression is given that the Steifel process has an advantage over the Mannesmann process in that it avoids the spiral arrangement of the fibres which exists in tubes made by the Mannesmann process.

This spiral arrangement of the fibres of the tube has been claimed to be one of the important merits of the Mannesmann process; and I think most engineers have accepted it as sound reasoning, at least for pipe subjected to internal pressure, although it might not prove an advantage where a pipe was to be subjected to transverse strains. It would be interesting to know whether there is any real objection to the Mannesmann tube on account of the spiral arrangement of its fibres.

Professor Carpenter.—In regard to the elastic limit I will take very great pleasure in putting in curves showing the extension of the material, and I think you will see that the elastic limit is very well defined indeed in the material.

In regard to the statement that the Mannesmann process hunts up defects, I would say that this information was obtained from a description written by a prominent employee in the Mannesmann factory. That view is evidently the impression of the men who are using the Mannesmann process.

Mr. Souther.—Perhaps I can try to answer that question in regard to the spiral structure of the Mannesmann tube. It may possibly exist in the early stages. After drawing the billet and after thorough annealing I have failed to find it in the microstructure or by any tests I have been able to devise. After the many annealings that take place during the process of drawing the finished tube, I certainly have not been able to find any spiral structure, and I have had some of the best experts on microstructure at work on it.

*Mr. P. J. Fickinger.**—It may not be out of place to state that the object of this paper was not, as would appear from the discussion, a commercial one, but one that would be of interest to this Society, inasmuch as there has not appeared in the transactions any description of the Mannesmann or kindred methods of tube-making. And to describe all methods that have been resorted to to produce tubes of a satisfactory nature would require a large volume.

Any one wishing to give the subject any particular study will find Edw. C. R. Marks's "Treatise on Iron and Steel Tubes" quite valuable. You will note that this paper says the tubing is seamless in the sense that no indication of the weld which existed in the original stock before drawing is visible in the finished product, nor could its position be ascertained when the samples were tested to destruction.

The writer was instructed to select a fair set of samples together with a piece of original stock (hence the indefinite term "original" in the report of tests) and take it to Sibley College and have it tested. The results were so much superior to expectations that on returning I selected a much larger number of samples and forwarded them to Professor Carpenter also, with the results that are before you, and judging from tests and requirements of users, feel justifiable in saying to any one doubtful regarding the seamless nature of this product, to find the seam.

Regarding the analysis of the steel employed, will say we

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* Author's closure, under the Rules.

have never had it tested, but making inquiry from two different sources, have received, viz.: Oliver Steel Co.—carbon .08-.10, man. 0.45, pho. .09-.10, sil. .009; Carnegie Steel Co., carbon .10, man. .30-.40, phos. and sulphur under .04. When we purchase the billets we require that it shall answer our purpose, and leave the mill the responsibility of production.

When people buy tubing they require that they shall stand their methods of construction. They are not buying the analysis; it is results they want.

That the tubing stands the vibratory strains, the results seem to indicate. That it is as good or better than some so-called high-carbon nickel-steel, or oil-annealed samples the gentleman alludes to as being so indefinite, I might say that I presume he can tell more regarding that special tube.

The term annealed, I will agree, is quite indefinite, and would be glad to substitute a better one. It means in this paper just what the gentleman understands—*i. e.*, relieving the tubes of strains due to cold-drawing.

That the Mannesmann system welds up the defects and does not give to the particles composing the tube a spiral direction, is new to me. What samples of Mannesmann tubes I have seen tested indicate that it does.

Regarding Steifel's process, patent No. 23,702 reads: "To pierce metallic blanks or billets in a heated state without subjecting them to a torsional strain or materially disturbing the longitudinal arrangement of the fibres of the metal."

Regarding the amount of acid for cleaning, I am aware that ½ of 1 per cent. will clean metal surfaces, but not rapidly enough. I have been in close touch with the wire business for the past ten years, and can say that the average practice is nearer 6 per cent. than anything else; the liquor being kept hot and subjecting the metal to the action a shorter time.

The pushing head is in operation at the McCool Tube Co.'s works, producing tubes down to ¼ inch diameter by 24 gauge.

Mr. Henning's remarks are very instructive and interesting, and, coming from recognized authority, are gratifying in the extreme.

*Prof. R. C. Carpenter.**—Mr. Souther raises the question as to the value of the tests given, from the fact that a full history of the

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*Author's closuer, under the Rules.

method of manufacture of the steel employed cannot be stated, and also that there is doubt respecting the exact composition of the steel. It is certainly worth considering whether or not this objection is a valid one. As I understand the point made by Mr. Souther, he considers that there is question regarding the uniformity of products produced in this manner, and there is a possibility that the samples furnished for testing were better than the average. To find out whether such a statement was based on reasonable grounds, the series of tests has been considerably extended and selections made at random from stock in such a manner that it would seem hardly possible that poor material should not be found if any existed. The results have been uniformly good, indicating to my mind that the process of drawing is of such a character as to improve the quality of the material employed. I am also fully satisfied that the average quality of the material is excellent, and that the process is such as to produce little or no inferior tubing. In regard to the tube marked "Annealed in Oil" and "Original," to which Mr. Souther refers as misleading, I would state that these tubes were supplied by the works with which he is connected and were marked in the manner described. I do not believe that the general public will be at all misled by the notation used. The McCool tubes were tested in the unannealed condition, which condition corresponded to that of leaving the draw frames, and also when annealed or after they had passed through the annealing furnace. The annealing is performed automatically in the manufacture or making of the McCool tubes and in such a manner that it is very difficult and nearly impossible for irregularities to occur; consequently what Mr. Souther states in regard to the uncertainties attending uniform annealing certainly does not apply to the McCool process, although it does, without doubt, suggest the cause of lack of uniformity which we have observed in tubes of many other makes.

Mr. Souther states that the elastic limit cannot be definitely determined in many makes of tubes, and in this respect I fully agree with him. As regards the McCool tubing, the elastic limit is as well defined as with a piece of steel of the same character, the strain diagram being essentially in every case of the same nature as the one submitted (see Fig. 190), which represents a tensile test of a McCool tube. The reduction in section, which is well shown in specimens 7 and 90, Fig. 186, also shows this characteristic well.

For these various reasons it seems entirely unnecessary that a history of the manufacture of the steel should accompany this discussion, although doubtless it would be a matter of much scientific interest.

The point which has been raised regarding the exact analysis of the steel is of much interest, especially for the reason that subsequent investigation shows this analysis to have been substantially correct, except that the amount of phosphorus was

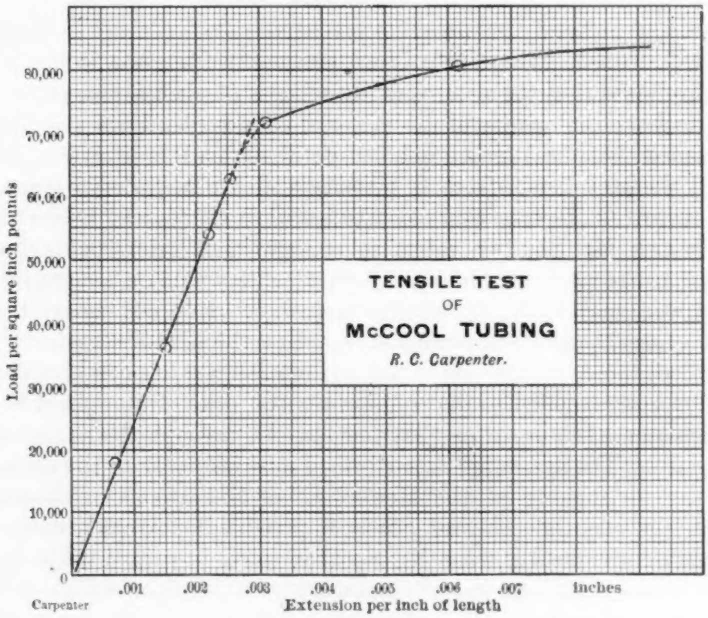

Fig. 190.

given somewhat too great. The tests indicate that this steel, which chemical analysis shows to be at least of only ordinary quality, forms, when treated in the manner described, tubing of excellent and even superior qualities.

Regarding the use of the word "seamless," I would say that it seems to me entirely fit and appropriate, for there is certainly no seam to be detected on the finished tubing either before or after fracture, and such is not the case with any so-called seamed or welded tubing.

DCCLXXXIV.*

THE HANGING AND SETTING OF THE HORIZONTAL FIRE-TUBE BOILER.

A PHILIPPIC ON THE COMMON METHOD, AND A METHOD OF REMEDY.

BY OROSCO C. WOOLSON, NEW YORK, N. Y.

(Member of the Society.)

IT may be recalled that in 1891 the writer had occasion to give his views as to the proper construction of a furnace for wood burning under boilers, which received some attention in the technical journals. At that time I felt that the common method of suspending boilers should be changed, and I adopted, among other features, a four-point link suspension, but in later years I have discarded the four-point suspension and have adopted a three-point suspension for substantial practical reasons.

The common method of hanging horizontal fire-tube boilers is, in my opinion, wrong, and I know of no reason why it is persisted in except that it is an antiquated custom, and therefore we continue it in a sort of indifferent, nothingless way, apparently not realizing that the world moves and we should move with it, or perhaps forgetting that the whole course of our existence is one continual development, and while it is the pride of some to become potent factors in this development, others take equal pride in accepting things as they find them and make the best of them, regarding it as a virtue in so doing on about the same theory that a sick man takes a dose of castor oil, because he has to.

At the time mentioned above I thought the discarding of side-brackets on the shell of a boiler and the adopting of four suspension lugs to take links were about right, but in later years I saw an improvement, and forthwith discarded the four-point suspension and adopted a three-point suspension for reasons which I will now explain.

While the four-point link suspension is far better than the rigid

* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

side-bracket bearing arrangement, it is open to one of the objections which the rigid bracket has, by becoming a three-point suspension, and yet not be discovered except by accident in some way, through the settling or bulging of the wall under the bracket. By reason of its different construction, the four-point link suspension does not change into a three-point suspension in the same secret way which is possible with side brackets, but it sometimes gets there, resulting in suspending the weight of the shell with its load of water and pipe connections, and sometimes more or less mason work on the top of the shell, upon three unequally distributed points. I have found this the case in a boiler hanging where the suspenders were made with an eye at the lower end, and a thread and nut at the upper end passing up between heavy crossbeams and taking a strap. The crossbeams rested on the outside walls simply, not having steel uprights to take the load off the walls. One wall having in time yielded a little, carried the crossbeams down with them, leaving the suspender slack, which necessarily threw the load on the other suspenders, and they, not being distributed to carry the load in this irregular way, brought a distortion on the shell, which is not a legitimate function for the shell and rivets of any boiler to stand.

Now let us turn to the virtues, if there be any, of the solid side-bracket suspension, leaving out the question of advantages or disadvantages of furnishing these brackets all in one casting or making them with a dove-tail construction. Many years ago the common practice was to let these side brackets rest directly upon the mason work. Later some one concluded that there should be an iron sole plate of some kind placed between the bracket and mason work, still preserving the same old cast-iron bracket with its more or less uneven bearing surface. Then the idea struck some one else that somehow the boiler was not quite so free to move fore and aft as it should be, and he introduced a series of rollers between the aforesaid plate and the uneven palm of the bracket. Some constructors use one roller, others use several, under each rear bracket, but on what theory the use of more than a single roller was based I cannot say, unless it was that if one roller was a benefit, several rollers must be more so, until at the present time the commonest practice is to use several rollers under each bracket except under the two forward ones. The forward brackets are supposed to be anchored in the walls which fix the boiler at this end.

Let us analyze first the construction, and next the erection, of this system in a boiler setting: In the first place, to have side brackets to perform creditably their function, the bearing face which is to rest on the rollers must have a perfectly true and smooth face. The faces of the brackets should be level or in line with the shell, both longitudinally and transversely. I will not argue the point, but simply ask, taking work as you find it, are they?

Now we have got the boiler blocked up in place, and the side walls are built up ready for the aforesaid sole plate to be masoned in under the brackets, and the mason finds, although a competent man, that his wall is just a little too high to get in the plate together with the rollers, and the quickest way out of the difficulty is to tear down a few courses and thin his joints sufficiently to give him a little leeway, so that when he comes up this time he will require to wedge up a little. He is all right so far as that goes; but those rollers must be put under the bracket and kept in proper position while he proceeds with his wall. Now there are, we will say, three of these rollers to go in, and we find that the under side of the bracket and the top of the plate are no exception to the regular run of all such work (rough), and we proceed to put all the rollers in what seems to be the proper place; but, when the sole plate comes to be wedged and pointed up we find only two of these rollers get a bearing, and are pinched, leaving the third to roll around at every jar or movement of the mason, or, what is quite as common an experience, one of the rollers will get a bearing on one end of it only and be perfectly free to swing around at the other, while the one which gets no bearing at all will simply rest there idly, still the wall is continued up, housing in the bracket completely, and the innocent engineer congratulates himself that he used all the rollers furnished him and soon forgets all about it.

I will now call your attention to other features of the roller practice. The roller which is found to get a bearing at one end only, when positioned practically square with the boiler, will not remain in that position, and the most natural thing for a mason to do is to see if by cutting it round a little it will not get pinched its entire length, and he finds that by cutting it round it accomplishes his thoughtless purpose, and forthwith cuts all the rollers round that are loose till they pinch, and so leaves them and bricks the bracket in.

Up to the present time the weight of the boiler is upon the blocking, but when that is removed those rollers which now stand in several different directions get the load and are supposed to provide an anti-friction bearing. Let us see how far this is the case. Out of three rollers under each rear bracket there is but one, we will say, carrying the load, and which stands exactly square with the boiler and is pinched its entire length (and that one I will wager stands on askew also). Of the other two, one is carrying no load at all, and the third is cut round sufficiently to cause one of two things when the shell of the boiler begins to expand and exert itself to move backward on those anti-friction (?) rollers, to wit: If the roller which is square with the boiler is carrying a little more load than the other one which is cut, the boiler will tend to move back in line, and the cut roller, not having the grip, will simply be slid over. On the other hand, if the cut roller has the greatest grip it will tend to crowd the boiler in whichever way the roller is cut, and the result is that something has got to yield, which unfortunately is the side walls.

There are some few constructors who have doubtless appreciated the evils of the common side bracket and roller practice, and have provided a cage, or sole plate with ribs on which the rollers rest, thereby reducing the chances somewhat of a roller getting cut round out of proper place. With the simple cage construction they should not stop, but should also plane off the bearing surface of the bracket if they wish to be consistent. After all, what is the result? An expensive and not highly satisfactory and only partially anti-friction bearing, subject to many conditions found an evil in the common roller bearing. The same criticism holds good in the ribbed sole plate also.

Doubtless there are those who will have side brackets on their boilers to the end of time. I perhaps should say "their time," for after that our children's children will only know of this construction as a matter of ancient history. To such a persistent advocate of the side bracket let me say a word. If the plan I have adopted, as shown in the accompanying drawings, does not appeal to your common sense, let us see if we can compromise, to wit: Leave out the rollers altogether, plane the bearing face of your bracket reasonably smooth, use a simple heavy cast-iron sole plate with upper face planed reasonably smooth. Now, when ready to set this plate, dope it well with common black lead and tallow and wedge it up solid under the bracket, preferably taking

care so to place it that the planer tool marks, if there be any, shall stand at right angles to the planing on the bracket, and you will have a more perfect anti-friction bearing than can be obtained with rollers. The only object in mixing in tallow is not to serve as a lubricant, but it is simply a medium to hold the black lead while the material is being applied, it being better to handle than dry lead, and the tallow will soon be gone after firing up, but the effect of the slippery black lead burnished into the two faces of the cast iron will last until the boiler is worn out. Even with this practical refinement you have still the brackets and certain evils therewith, which the steel ears (hereafter explained) and suspended equalizing bar eliminate, and which will be found much superior and will cost no more to install.

I am not yet through with my philippic. Let us assume that each of the three rollers under the side brackets are all loaded alike, and that they stand mathematically square with the boiler, and that no bits of brick, slate, or other foreign substance are left alongside of the rollers, and that we are going to take advantage of all there is in roller anti-friction construction, so that so far as that system goes we have got perfection itself. What do we do next? I will explain just what is being done every day where this bracket and roller construction are used. We deliberately go to work and close in the brickwork against the sides of the boiler, chipping out the brick to fit over rivet heads, driving the brick in against and around the laps of the sheets of shell, and using every effort to make a gas-tight joint, thereby as completely and thoroughly anchoring the boiler into the mason work as it is possible to do with bricks and cement mortar, PREVENTING ABSOLUTELY THE MOVEMENT OF THE BOILER IN ANY DIRECTION EXCEPT IT TAKE THE BRICK SETTING ALONG WITH IT.

If this practice (and it is the method in vogue everywhere to-day, even so near the twentieth century) is not a *casus belli*, what is? And yet because of its commonness we overlook it.

Again, it is the practice with some to spring the back arch over against the rear head of the boiler. There is no excuse whatever for this. Others spring the arch across from side to side, leaving space between the side of the arch and the head of the boiler. This is one step toward improvement, but which is at best a short step when you take into consideration the difficulty of maintaining an arch built in this direction, and also of

preserving a free expanding space and still maintain an air-tight chamber.

Another feature of the common every-day boiler setting which is open to criticism is the prevailing method of setting and fastening the buck stays.

These stays are set up against the wall for the purpose of reinforcing them, not to assist in cracking them, and yet the common method of setting and fastening these stays is, in the majority of instances, the direct cause for the walls cracking.

How many stays after being set up do we find bear against the wall the whole length of the stay? Possibly one in a hundred. The other ninety-nine get a bearing at the bottom, and then very likely do not strike the wall again until it reaches the top. This practice is inexcusable, especially when it is so simple to remedy. These stays are commonly bound to the walls by an anchor bolt at the bottom, and a long over-all binding bolt, or rod, at the top.

Let us digest this combined misconstruction a little. In the first place, we have robbed this buck of its staying function by reason of not having brought it to a bearing against the wall properly, and in the second place we have provided a clamping apparatus so fastened at top and bottom that the natural expanding of the boiler (or, what is an appropriate expression, the breathing of the boiler) when in duty tends to do, and does do, the very thing the stays are designed to prevent.

The long over-all buck stay rods at the tops are used for two reasons: one is that because our grandfathers used them we must, and the other is that there is no other way provided for clamping the stays with the present construction of horizontal fire-tube boilers.

These long rods being exposed do not expand as the boiler and brickwork do, therefore we bind the stays in the same relative distance apart, whether the boiler is hot or cold, and the stay which gets a bearing against the brickwork at the top and bottom only must crack your wall or break the rod, and possibly you do not need me to tell you that it is the wall which suffers.

There is the same tendency to crack the walls, even if the stay gets a bearing its full length, provided it is bolted in the same old way, but the cracking manifests itself in a different place.

If the time should come when heat will not expand or cold

contract matter, then we can continue staying our boilers and fastening our stays in this way and run no risk of having our wall go to pieces; but until then I regard it a duty to improve on the old methods.

This ends my philippic, and I beg to ask you now to turn to a method of hanging and setting a horizontal fire-tube boiler which I believe to be superior in every particular. (Figs. 191 and 192.)

First.—Hang the boiler at three points only. The rear point is to sustain two-thirds of the total weight of the boiler, and becomes the swinging point.

Second.—This rear point is to sustain its load entirely clear of the brickwork, upon cross channels which rest, at their extremities, on steel uprights.

In the centre of this crossbeam there is located a cast-iron saddle in which the swinging-pin rests, and from this pin a steel strap is suspended, which spans at its lower end a heavy steel equalizing bar, to which it is connected by steel pins also. At the extremities of this bar there are pinned steel links, to which the weight of the rear portion of the boiler is hung. It is obvious, therefore, that there is no influence exerted by this arrangement, except to swing the boiler, leaving it perfectly free to go and come, as influenced by expansion and contraction or from any other cause. By the interposing of this equalizing bar we avoid any possibility of bringing strains or distortions into the shell of our boiler, or side thrusts into our brickwork, if for any reason the loaded foundations or side walls should settle, and there is less likelihood of getting the boiler out of its exact position when removing the blocking, and we are also enabled to raise or depress the rear end of the boiler to accommodate piping, blow-off, etc., with ease and accuracy by removing or adding the necessary shims under the centre saddle, and when finished it is not susceptible of being tampered with. No planing or tooling of any kind other than the drilling of pinholes is necessary for this construction.

Third.—The two forward supports each carry one-sixth of the total weight of the boiler, and consist of steel ears reaching out from the shell and resting upon long cast-iron shoes set out flush with the outside walls, thus bringing this weight of the boiler upon the red brick walls and entirely off the firebrick lining of the fur-

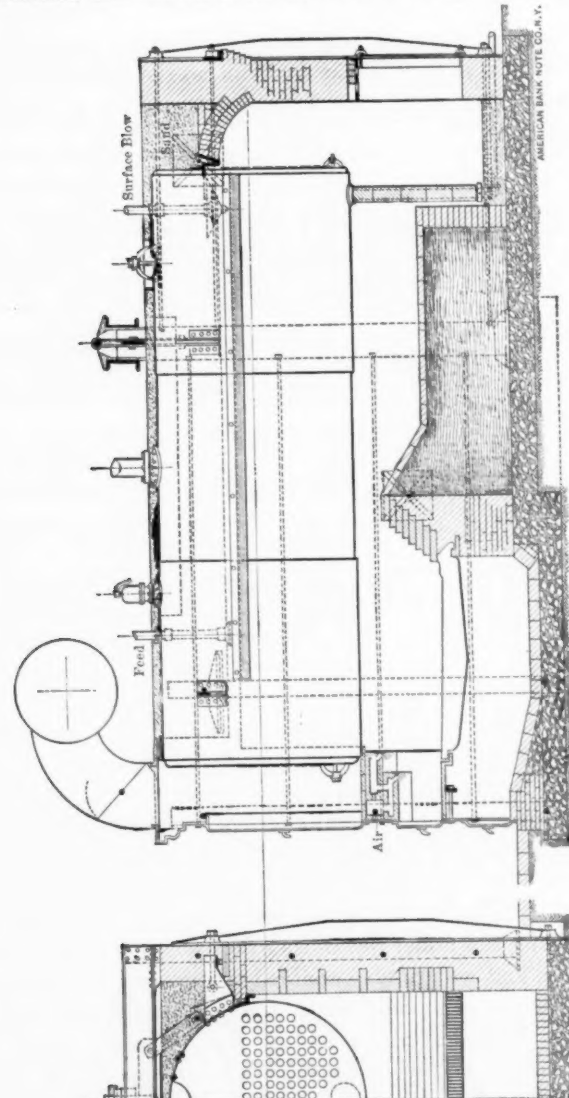

FIG. 192.

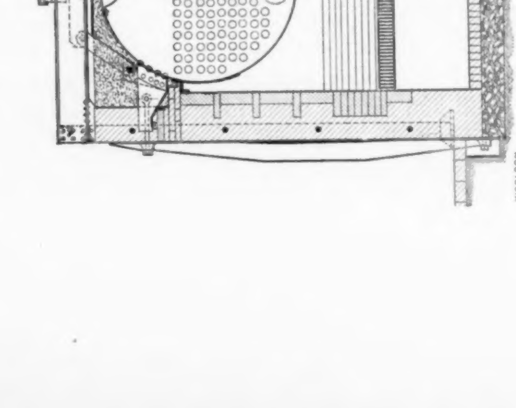

FIG. 191.

nace. These ears are masoned solid into the brickwork, thus fixing the boiler against any fore and aft movement at this point. The shoes are made the depth of a brick and three bricks in length, providing thereby a very liberal distribution of its load. In setting these shoes it is simply necessary to bring one side flush with the outside wall, and wedge and point it up snug under the steel ear, the ordinary mason work being sufficiently level for these plates. All the rest will take care of itself. Where two or more boilers set in one battery, the aforesaid ears lap by one another on the same sole plate and are bolted together to afford a maximum resistance for the furnace buck stay anchorage. These ears are riveted or bolted in between heavy steel angle irons, which are riveted to the shell, when the boiler is erected, but are shipped separate from the shell.

Fourth.—The set of buck stays shown alongside of the furnace wall are anchored at the bottom in the usual manner, but at the top their anchor bolts hook on to the ears of the shell, thus avoiding a long rod over the top of the shell (long rods not yielding to the "breathing" of the boiler when heated up and cooled down), and always preserving a secure hold of the brick-work, keeping it relatively up to the boiler under all conditions of expansion and contraction of the shell, for brickwork is quite capable of accommodating itself if you will only give it a chance.

Fifth.—After providing perfect means for the movement of the shell, fore and aft, it would avail us nothing if we are to brick the shell in solid in the usual way (but we are not), for every rivet head and lap serves to anchor the shell in the brickwork as mentioned before, resulting in cracking and general dilapidation of the walls. To overcome this I rivet a heavy 3-inch Z bar to the shell on each side. The outer face of this bar is straight and smooth, and up against it I bring the inside face of the furnace wall, and over the top of this Z bar carry two courses of brick to within an inch or two of the shell of the boiler, thus closing the joint as plainly shown on the drawing. Bearing in mind that the rear point of suspension exerts no influence to crowd the boiler sideways, it is logical to assume that its movement, fore and aft, will be perfectly free and independent of brickwork on the sides.

Sixth.—With the above arrangement alone we will not yet be free of all brickwork, for the rear cross wall must be considered. Therefore we provide a heavy V-shaped cast-iron beam placed across the back chamber, securely masoned in at each end. This

beam is placed away from the boiler head about $1\frac{1}{4}$ inches. This is shown in large scale on Fig. 193 at *A* and *A'*. Over the short leg of this beam laps one leg of an angle iron which is riveted to the rear head of the boiler. This angle iron is cut just the length required between the side walls of the combustion chamber; the vertical leg near the extreme ends is cut to a pattern, and these ends turned down flat with the horizontal leg; this turned down portion fits round the curve of the boiler head, thus altogether forming a tight joint. The long leg of the cast-iron beam forms a buttress over against which the back arch is sprung, thus forming an arch not only laid in the proper direction, but provides liberal head room on the sides as well as in the middle of the boiler. The first engineer to use this style of arch beam was, I think, I. V. Holmes, but it is improved by having a series of depressions on the long face as shown. With these depressions the brick arch gets a better anchorage, not only to stand its own weight and the sand filling above, but the occasional weight of the workman who finds it necessary to stand upon it. Back of this arch, on the outside of the rear cross wall, is placed a horizontal buck stay, anchored by bolts extending through to the upright steel standards. This takes the thrust of the arch, which will then last indefinitely.

The foregoing completes a combination of iron and brickwork for hanging and inclosing a boiler of any size and any number of them, leaving them free to take such position as heat and cold and other influences demand, without straining any part or crowding the brickwork out of shape, and, furthermore, permits the removing of the fire-brick lining without disturbing the main setting, and if for any cause the entire brickwork is required to be removed it can be done without interfering with the position of the boiler, for the rear suspension with the two-thirds load takes care of itself, while it is simply necessary to suspend temporarily the forward light load by catching the steel ears through the buck-stay bolt holes, thus leaving full clearance to work below.

The following are accessories which I have found to possess practical merit (Fig. 193):

First.—Where a blow-off pipe is preferably located at the rear, I use a fire-clay sleeve, which can now be readily procured in the market, being made of different sizes and provided with male and female ends. Simply slip on a few of these over the blow-off

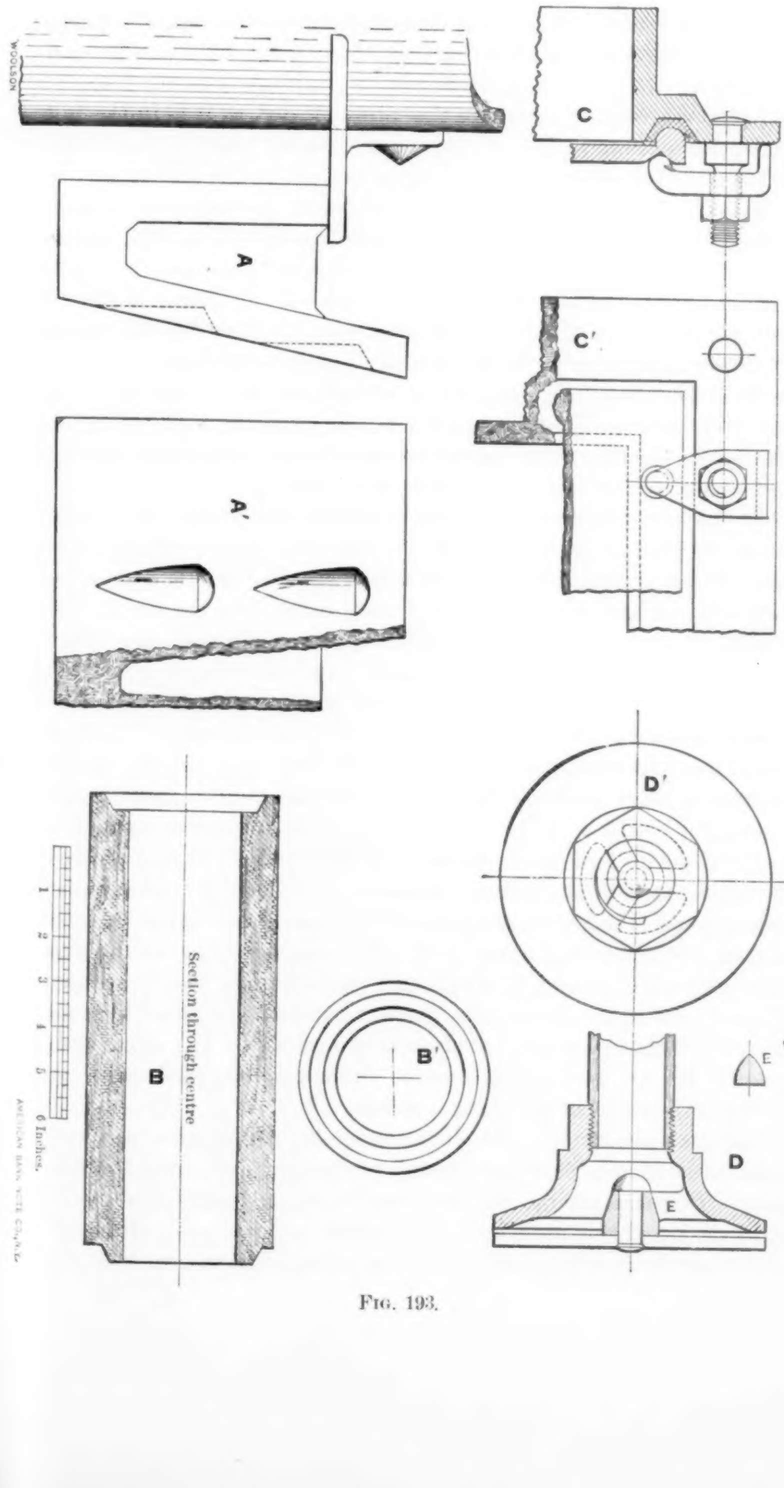
WOOLSON
A
A′
C
C′
D′
B
Section through centre
B′
1
2
3
4
5
6 Inches.
E
D
E
AMERICAN BANK NOTE CO., N.Y.

FIG. 193.

pipe, first placing in a little fire-clay paste between the ends, forcing them together and holding them there by a collar and set screw.

These sleeves will preserve the pipe, located as it is in the hot gases, for a great length of time, doubtless as long as the boiler will last. It is shown on Fig. 193 and is marked B and B^1.

Second.—The cleaning-out door and frame is simple and cheap, but perfectly air-tight. This is shown in detail on Fig. 193, and is marked C and C^1.

There is an annular recess on the face of the frame about $1\frac{1}{4}$ inches wide and $\frac{9}{16}$ of an inch deep, into which is filled fire-clay paste when the door is ready to be closed. The inside face of the door, around the edge, has cast on it a half round bead, which, when the door is closed, forces itself into the fire-clay and forms an absolutely air-tight joint, regardless whether the casting is smooth and true or otherwise. No tooling is necessary.

At the two corners of the door opposite the hinges are riveted studs, on which lipped straps fit instead of a latch. These have been found better than a latch, which requires to be forced together a certain degree before it will catch, but the strap and stud can be screwed up till the joint is made snug and then left.

Counter-sinking a spot in the back of the door for the lip of the strap to fit in assures the strap standing in its proper place whether a man closes up the door in the light or in the dark. Furthermore, it is a very cheap door to make, besides being air-tight. It is not necessary to apply clay every time the door is opened and closed, for it will be found that this clay will not easily drop out.

Third.—The feed head shown in detail on Fig. 193, and marked D and D^1, is, I think, a great improvement over the common perforated pipe. It produces what could properly be termed a film feed as distinct from a spray feed. My object is to avoid the discharge of a large body of water and yet maintain the necessary volume, and at the same time prevent as much as possible a liability to choke up or get out of order in any way. The one shown here is, in my estimation, correct for a reliable feed head or nozzle, and is withal simple and cheap.

The cut showing the side elevation of the boiler gives a pretty clear idea of the chambered and perforated arch over the fire door. This is made up of special arch brick. Some eight years ago I designed this arch for a plant which had had great difficulty in getting an arch to stand twelve months. There has been no

trouble since. The peculiarities of bridge wall construction and such other details as go to make up a substantial and practical setting I will not go into here, for most engineers have their own ideas, and time is too fleeting to argue minor matters about a boiler installation.

DISCUSSION.

Mr. Charles W. Barnaby.—It seems to me that there is a good deal of unnecessary refinement on the part of some in their ideas of setting a boiler. We find a good many different methods of hanging boilers in the specifications which we receive at our works. One in particular I call to mind in which the rear end of the boiler had to be suspended on $1\frac{1}{2}$-inch hardened and ground balls and the V guides or seats had to be made of steel or iron planed and finished all over and case-hardened. While the party who drew up the specifications considered it necessary to make such refined provision for the longitudinal expansion of the boiler —the distance was only thirteen feet between centres of front and rear brackets—he entirely lost sight of expansion sidewise. There was no provision whatever for side expansion. It was about eight feet from centre to centre of ball supports sidewise, so there was almost two-thirds the expansion sidewise that there was longitudinally, and it struck me as rather odd that any one who would lose so much sleep over the expansion longitudinally would entirely lose sight of the side expansion and go to so much trouble and expense to provide for the one and none whatever to provide for the other.

I notice that the front brackets on the boiler suspension advocated in Mr. Woolson's paper extend out some fifteen or, possibly, eighteen inches, so that the support is some eighteen inches from the shell of the boiler. The base of the bracket on the boiler is possibly about half this amount. I have often wondered that some of these people who borrow so much trouble over the suspension of a boiler do not worry for fear that the leverage, due to the fact that the extension of the brackets is about double the base attached to the boiler, will not tear a piece out of the side of the boiler. It seems to me that there is a good deal more danger of the bracket pulling a piece out of the boiler shell than of any damage resulting from the torsional strain on the boiler due to the support giving way under one of four brackets.

There is one point in the paper to which I want to take excep-

tion, and that is in regard to what takes place in case one of the brackets on a boiler supported in the ordinary way on four brackets is relieved of its support. The author states that when the masonry settles under one bracket, in such case the load will be thrown upon the other three—that the boiler will be on a three-point suspension basis. Now, I think it would be on a two-point suspension basis. If you take the support from under one bracket you also relieve the load on the diagonally opposite bracket, and the other two diagonally opposite brackets take up the whole load of the boiler. I have made no calculations, but as a matter of judgment I should say that the torsional stress due to the weight of the boiler and the water in it would be infinitesimal in proportion to the strength of the boiler; that it would not be worth considering. It might be interesting to make a calculation on that point, but the diameter of the boiler is so great that it seems as if the torsional stress, which would come principally on the girth seams, and slightly on the longitudinal, would be so slight in proportion to the strength of the shell that it would not be worth taking into consideration. The stress thrown on the shell by this torsional action would not be in the same direction as the strain produced by the pressure in the boiler; it would not act in conjunction with the bursting strain; so that it seems to me that it would not produce any noticeable result.

In regard to the slight particle of slate or little piece of brick or something of that kind getting under the roller, it does not strike me that that would be anything serious. If a boiler can tear a massive wall to pieces in the way that the author points out, it seems to me that about the first time that it expanded, if there happened to be a little corner of slate or something under the roller, it would be crushed and would be out of the way before the second expansion. Nothing that could materially obstruct the movement of the roller could get under it unless some one should take the trouble to wedge a piece of steel or other hard metal under the whole length of the roller with malicious forethought.

Mr. Ezra Fawcett.—The object of the paper, it is presumed, is to provide for equally sustaining the weight of the boiler at all points, to allow ample latitude for expansion, and to eliminate the distortion consequent on supporting the boiler by four brackets if the supporting wall should settle more at one point than

another. Hanging the boiler at three points with an equalizing bar avoids distortion. The absence of long brackets and the dome extending out from the shell of the boiler greatly facilitate the transportation of the boiler and its handling. The general features of the paper are well presented, and the method should work well in practice.

Mr. James McBride.—In connection with this matter I am reminded of my boyhood days when, with other boys in front of the country grocery store, we were discussing the best method of hanging a mowing scythe. One of the boys who had been born tired said that he liked his best hung on the fence. So I think the best way to hang a fire-tube boiler is to hang it on the fence. However, for the benefit of those so unfortunate as to have or who are likely to have this style of boiler, I am glad to see somebody has got courage enough to start the ball rolling and devise some method for improving the setting of it.

I think Mr. Woolson's devices are entirely too refined. It seems to me that all which is required is to hang the boiler in the furnace at two points. You cannot very well hang it upon one—hang it at two points. Make it as distinct from the brickwork as possible. I have had twenty-one of them for nearly twenty years, and they have cost me hundreds of dollars every year for labor alone and a large amount of money for material to keep them in repair, and, while what Mr. Woolson says is true, I think that he has taken a method of obviating it which is entirely too refined for general purposes. I think people who contemplate buying boilers should buy boilers which don't have to hang at all.

Mr. Francis H. Boyer.—I am in sympathy with the two preceding speakers for the reason that I am operating and not building boilers. I should think that Mr. Woolson is contemplating mounting boilers on stilts and marching them around over the country. We have some pipe boilers, but where conditions permit, we invariably use horizontal tubular boilers, although I would say that not long since I had occasion to tear down the walls of one of my boilers which had been running sixteen years, and the gentleman who furnished the design for setting that boiler placed the rollers under the lugs, and the rollers were put in lengthwise of the boiler. Now, that boiler had worked for sixteen years and had done its work perfectly. We never had any trouble with it, and I am not positive that this is not a good way to place the rollers. When you stop to think for a moment that the slight

amount of expansion that the boiler has, probably a two-hundredth part of an inch, probably not over the two or three-hundredth part of an inch that it goes, due to the expansion and contraction of the metal itself, the question of expansion is hardly worthy of consideration. Instead of hanging my boiler from one, two, or three points, especially if it is a boiler with lugs on the sides, I would put six lugs on the boiler, three on each side. I have taken out boilers when I have found twenty-four inches from the lug down that the wall would be entirely destroyed. If we have six carrying points and the wall becomes destroyed alongside the furnace, we have four left to carry the boiler's weight. There are two parties in boiler making and engineering: one is the fellow who builds the boiler and the other is the fellow who operates it. Now we look at it from the operating and the repairing condition, and we try to get it in such a position that when it is in bad shape by neglect or from any other cause it will do no harm. I think the tendency of design work is going unnecessarily too far—too much of an outlay of money—the drawing of these fine points. I furthermore believe that the whole result can be had satisfactorily in some of the old methods, and am positive that imagination and the pencil enter largely into the results which are given out by the new departure in steam boiler generator over our old friend the horizontal tubular.

Mr. H. H. Suplee.—Mr. Woolson, in his paper, seems to object to hanging the boiler on the brickwork, and he only really suspends it at the back end and only allows the front portion to run on the bricks. I do not see why his whole purpose would not be obtained—and that I think was Mr. McBride's idea—by having two posts and the cross-beam fronts and two links being entirely independent of the brickwork. Mr. Woolson refers to the ease with which you can take down all the brickwork and reset it if you prop up the front end. If the front end is propped up from the beginning so that the boiler stands on its stilts from the start, you would not have to bother about the brickwork. I know of a number of boilers hung that way, and they have stood very well.

Mr. Gus. C. Henning.—I notice that Mr. Woolson, in his paper, describes a point of attachment at the forward end which seems to me a questionable point by which to hang up a boiler, as one wall of the furnace may be hotter than the other and that one wall will either bulge out one way and tilt in the other direction, causing the buck stay-bolt to yield and move back. In another

case one wall expands more than the other, and the bearing will come on the higher lug and on the rear hanger, which of course produces a tremendous strain on the front connection, which will cause the boiler to bend so as to buckle the shell of the boiler on one side. If it had been hung up on the front end, where there is some stiffening, due to the tube-sheet or the head and the flange, the hanger would be in the same position on the side, but it would not buckle the boiler. There would be considerable working at the side, which always comes on the horizontal seam, being a particularly bad spot for motion. This is the usual result when a boiler is hung as Mr. Woolson proposes, because he catches hold above the seam and in a place where the boiler is not stayed at all. If it were attached forward about the horizontal seam, where the boiler is reënforced by the plate, no bending strains would arise in the shell. Of course the working of the boiler is the cause that opens seams, and injures them more than anything else, and, with that point in view, I think the attachment should not be as shown. Of course a hung boiler will avoid a great many troubles that are found in those that are fixed. At the same time we know that a boiler hung, as shown, frequently works forward and back, and when the boiler, in some manner unexplained, due to the dripping of water or otherwise, rusts fast, it will stick and the wall connections will be forced. The trouble is that walls that are hung as shown do not remain in position, as it is a common occurrence that one wall is hotter than the other. These causes produce unnecessary strain. The ordinary boiler may be set on four lugs. That is, one wall will expand or contract differently from the other, but still the boiler will remain on these lugs; but the boiler should be tied to its position so that it cannot work off the bearings, because it may oscillate forward and back even when set on rollers. I think the points of suspension should be selected with the utmost care. I do not believe that the point of suspension shown is as good as another that might be selected, for the same reason that it comes on the point of the boiler where there is no stay from side to side. Of course if there is any working at all the sheets will bend and will have an oscillating motion all the time, because we know that the shell works in different parts differently. It is not simply expanding and contracting, but the boiler works under the changes of heat and the position of the boiler just as much as though acted upon locally by pressure or otherwise.

Mr. G. W. Bissell.—While agreeing in the main with the conclusions of the writer of this valuable paper, it would seem as though there is some inconsistency in allowing the boiler to rest on any part of the brickwork of the setting. It is oftentimes convenient to be able to tear down a setting for repairs, especially at the front end, where repairs are most often needed. It sometimes happens also that one or both walls of the boiler setting have to be changed, as when new boilers are added to form a battery. It is also convenient in the erection of a boiler to be able to hang the same from girders and to leave the space under the boiler free of blocking, thus facilitating the work of the bricklayer. Since putting in the boiler described in my paper at the last meeting, I have in several instances employed the same general principles of hanging the boiler as I there described, and am quite strongly convinced that the boiler should be completely suspended and should not rest in any way upon the setting. When setting boilers by this method I usually hang them about one inch above their final position, throw a brick arch over the shell, using the latter as a form, and when the brickwork is complete the boiler is lowered about an inch, thereby leaving the same unbound by the brickwork and providing an air space over the top.

Mr. William H. Bryan.—Mr. Woolson's objections as to the ordinary method of hanging the horizontal return tubular boiler are well taken. It must be remembered, however, that this plan of lugs, rollers, and plates is quite inexpensive, and for this reason alone will continue to be used to some extent, in spite of the grave objections to it. Bad as it is, it is still a great improvement over the old methods. On Mississippi River steamers and in some stationary plants in the Mississippi River Valley, which follow river practice, many of the boilers are still supported on columns cast with the boiler front, and cast-iron stands under the mud-drums at the extreme rear end.

Unless low first cost is imperative, boilers should always be hung from overhead. I have designed a number of systems for this purpose. The use of cast iron or structural steel columns at the sides to support the cross-beams is desirable, but adds greatly to the cost. As a compromise I frequently rest the beams on the side walls on heavy cast or wrought iron plates, distributing the weight over a considerable area. In such cases the air space in the masonry must be omitted underneath the supporting plates.

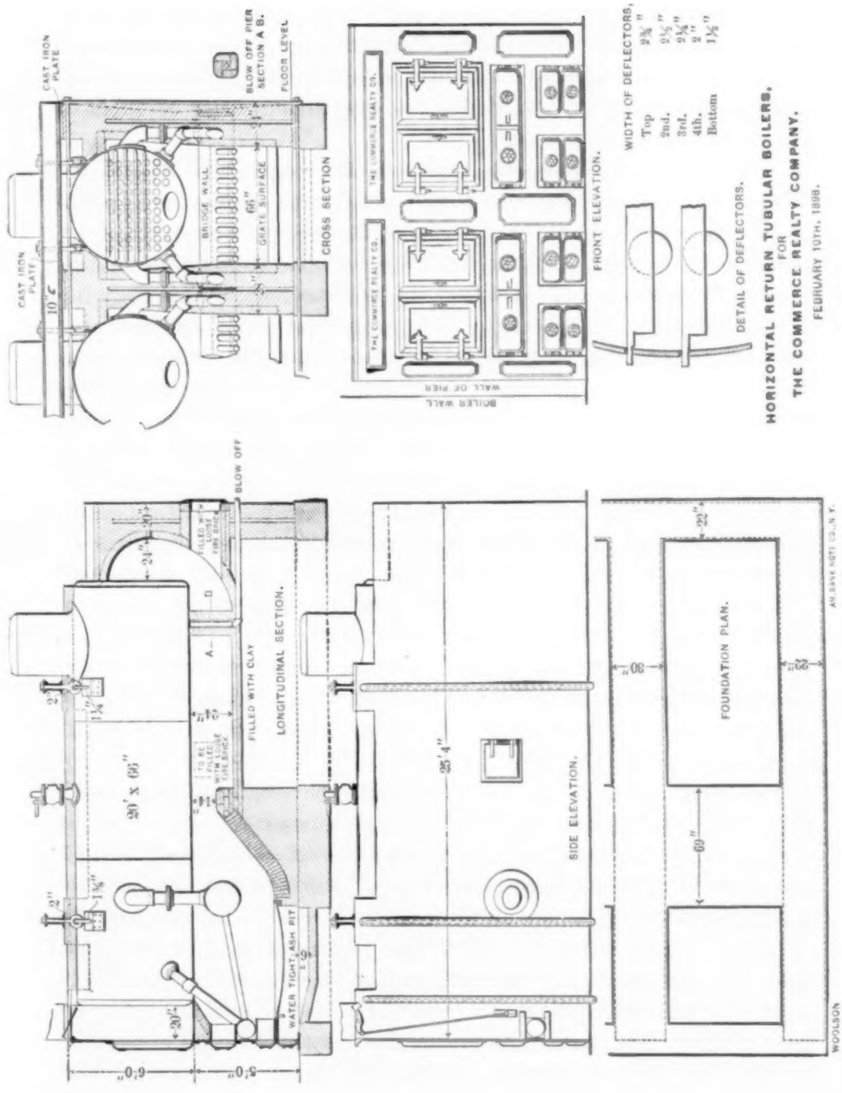
CAST IRON PLATE
CAST IRON PLATE
BLOW OFF PIER SECTION A B.
FLOOR LEVEL
BRIDGE WALL.
66"
GRATE SURFACE
CROSS SECTION
THE COMMERCE REALTY CO.
THE COMMERCE REALTY CO.
BOILER WALL
WALL OF PIER
FRONT ELEVATION.
WIDTH OF DEFLECTORS,
Top 2¾"
2nd. 2½"
3rd. 2¼"
4th. 2"
Bottom 1½"
DETAIL OF DEFLECTORS.
HORIZONTAL RETURN TUBULAR BOILERS,
FOR
THE COMMERCE REALTY COMPANY.
FEBRUARY 10TH, 1898.
BLOW OFF
FILLED WITH CLAY
LONGITUDINAL SECTION.
WATER TIGHT ASH PIT
20' x 66"
SIDE ELEVATION.
35' 4"
FOUNDATION PLAN.
WOOLSON

FIG. 194.

Fig. 193 indicates my most recent practice; the cross-beams being channels, and links being used to connect the eyebolts to the lugs riveted to the boiler shell.

The drawing also shows some other points which may be interesting—such as the down-draft furnace, location of steam dome at the extreme rear to get the dry steam, circular return at rear end of the furnaces, and deflectors over front ends of tubes to distribute the gases better.

This setting is, of course, open to the objections which Mr. Woolson mentions, that the entire weight may come on three of the bolts. This should not happen, however, if the engineer attends to his duties. It is as much his business to keep these nuts properly adjusted as it is to keep the boilers clean. This drawing is also open to the objection that proper provision has not been made for expansion and contraction of the boiler without interfering with the brickwork. A simple computation shows the expansion of a 16-inch boiler between 32 degrees Fahr. and the temperature of steam at 100 pounds to be $\frac{3}{8}$ of an inch, which is certainly too much to be disregarded.

Mr. T. W. Hugo.—I presume that one reason for still retaining the practice of suspending a boiler by brackets resting on the wall, or otherwise, is the question of cost, which certainly should and does come into the calculation, but it seems almost too much refinement for the ordinary boiler if we adopt Mr. Woolson's plan. I do not approve of the usual custom of using brackets, and desire to call to your attention to a practice which has given us good satisfaction in the Northwest. I am not aware whether or not it is common in the East.

The first sheet of the boiler extends beyond the front head about nine inches and rests on the boiler front casting, which is made a little heavier than the ordinary front, while the rear end of the boiler rests on a concave roller, which is placed on a saddle-piece supported by a pier of firebrick. There are thus two points of support, and, when it is fired up, the boiler is free to adjust itself to conform to any strain that may be put on it. The brickwork is continued up over the boiler at a distance of from two to four inches. The space thus formed becomes filled with a hot gas, or other products of combustion, and the flame is prevented from sweeping over the boiler by check walls and, in some cases, a backbone of brick is placed on the top, resting on the boiler, but nothing interferes with the easy adjustment of the boiler to

conform to any strain, and that without injuring the brickwork. We find that the repairs account is reduced to a minimum. I have in mind boilers so set which have not been touched for eleven years until last winter, and then we had merely to point up the joints, and others which have lasted nine years without requiring any repairs, but in all those cases the boilers were well set in the first place, which is the great secret of an economical setting.

Mr. McBride.—I agree with the last speaker in regard to the question of cost. I think it is very largely a question of cost why those boilers are set in that way. The boiler in itself has such a factor of safety over any strains that are likely to be brought on simply by the weight of the boiler itself, that I think many of those refinements can be entirely disregarded. I had some boilers set as the last speaker mentioned. The front rested on the fire front, and about two feet from the back end rested upon a cast-iron leg set upon a brick pier. The piers burnt out. I had them built of the best ordinary sized firebrick. They burnt out every few months. I replaced them with firebrick made six inches thick, twelve inches wide, and two feet long, two of them to one layer, and crossed them. They also burnt out, and the thing became such an intolerable nuisance that I discarded them altogether, and riveted lugs on the back end of the boiler to support it. You can set one of those fire-tube boilers and run it for fifteen or twenty years, and it may be just as good almost as the day you set it. But take the same boiler and take out every particle of work it is capable of giving and your furnaces are going to burn out. So I think the reasonable thing to do is to hang it up by ears at the top and let it go where it has a mind to. Let it go and take the brickwork with it; that is better than it is to attempt to fasten it any way and put an extra strain on it.

If a boiler can be hung in a furnace independent of the brickwork entirely, the furnace will last very much longer than if it is attached to it in any way whatever.

Mr. Barnaby.—I would like to ask for a little information concerning the expansion of boilers. A speaker has said that the expansion of a boiler was about $\frac{3}{8}$ of an inch in its length. Less than a month ago a man who has had considerable experience in the design and sale of boilers told me that a paper was recently published, I think in Germany, where they had made elaborate experiments and determined that there was actually no expansion

whatever to a steam boiler. I would like to inquire whether there are any of the members present who have seen such an article. I told him I thought there must be some mistake about it, because that was contrary to all previous theory and experience as to the effect of heat upon metals; but he said that there had been an elaborate experiment made, and that it was the same length when heated as it was when cold. There is quite a difference between his statements and the $\frac{3}{8}$ of an inch expansion that the gentleman has just given us.

Mr. Boyer.—There is one thing in setting a boiler to which I do not think attention has been called, and that is the steam connection from the boiler. It is oftentimes the case that the steam pipe leaves immediately from the top of the boiler. In our country we do not attach steam drums to boilers. I find that question of applying steam drums has a great deal to do with locality. We build without steam drums, making a cast-iron neck for steam connections, rarely going to the end of the boiler before we connect it into a large steam pipe with usual junction valves. There is one objection Mr. McBride has brought of supporting the boiler in front and having the expansion at the back. There you throw the entire contraction and expansion on that steam pipe, on the fittings and everything joined with it, and yet it is rare that we hear of the connections rupturing. I think in our town we have had in the last year three large breaks of steam pipes, and invariably they have been in the steam line outside of the boiler room. Here we have a battery of boilers, and it is necessary to let one down in the centre or draw the fire for cleaning. Here come this expansion and contraction, and the strain must be taken up on the pipe. There is the danger point. I am inclined to think that this entire question overawes engineers. I do not believe there is half in it they think there is. Take our sectional tubular boilers—I think the danger is multiplied until it becomes a great big bugbear.

Mr. Henning.—I would like to say that, although the expansion of the boiler is very slight, we are talking now about the relative expansion between the boiler and its setting, and, if the brick expands one inch and the boiler one-eighth of an inch, it produces just the same effect as if the boiler expanded one inch and the setting remained the same. Say the boiler is heated to the proper condition—expansion under 500 degrees is very small indeed. A boiler fifteen feet long would not expand one-eighth of an inch,

but it is the setting that expands. Under the same temperature, under the temperature of the boiler of 500 degrees, due to the steam, the temperature in the furnace and linings is at the time 2,500 degrees. The brickwork of any kind expands under that condition at least two inches and a half for fifteen feet in length, if it were all at a temperature of 2,500 degrees, but as the outside is colder than the inside, the expansion of the setting is less than an inch, or about that. It is hardly the expansion of the boiler itself that causes the trouble, but that of the setting.

Mr. McBride.—In answer to Mr. Barnaby's question about expansion, I can say that about twenty years ago I measured a boiler under the temperature due to about 125 pounds of steam. The boiler, if I recollect, was 18 or 20 feet long, and I recall very distinctly that the expansion was about $\frac{3}{8}$ of an inch. The expansion of a 16-foot boiler between 70 degrees and 350, accordingly to the coefficient of expansion of wrought iron, would be about .35 of an inch.

Mr. Bryan.—My figure, $\frac{3}{8}$ of an inch, was simply computation based on the assumption that the temperature of the shell was the same as the steam inside. It was taken from 32 degrees.

Colonel Meier.—I have measured a boiler just as Mr. McBride said, and found $\frac{5}{16}$ of an inch expansion for a 16-foot boiler. I measured it at the rear end and the front end both. I had plumb-lines both at the front and rear ends. The front end was fixed.

Mr. Henning.—Did you measure at the bottom of the boiler as well as at the top?

Colonel Meier.—At both top and bottom.

Mr. Henning.—Was it the same at the top as at the bottom?

Colonel Meier.—There was a slight difference. It was a water-tube boiler. It was not like those "hung on a fence."

Mr. Henning.—The expansion at the bottom is about twice as much as at the top.

Colonel Meier.—This was a water-tube boiler, and the difference between the top and the bottom was not quite a sixteenth of an inch.

Mr. Charles W. Baker.—I would like to ask Mr. Henning how he knows the expansion at the bottom is double what it is at the top.

Mr. Henning.—By putting notched iron rods through the back wall, and measuring at the top, and doing the same thing at the bottom. I tried to find out where the trouble with some boilers

I had set up arose, and I found that it was partly due to the change of shape of the boiler, because the tubes were in the bottom and there were not any tubes in the top, and the expansion of the tubes and the shell having the fire below and the fire through the tubes and no fire on top caused that part of the boiler to expand very much more than the top. I simply put rods through holes in the setting, and I found at once that the boiler was very much longer and had actually sagged in the middle on account of the distortion of the boiler. The boiler does not remain a cylinder, but becomes an annulus of a ring of a very large curve, and somewhat on account of the setting as well. The principal forces are at the bottom and, as that expands, the top not expanding as fast, the temperature not being as high, the boiler is distorted. It is one of the most difficult things to say what a boiler really does do, but it is not so difficult to say what the setting does, because that can be measured from outside points; but there is no setting that ever expands the same at four different points.

Mr. Barnaby.—I would like to ask Mr. Henning whether that boiler was perfectly clean, or had scale on the inside.

Mr. Henning.—Two boilers had just been set and, after the second week's operation, we found some trouble and some breaking of connections. Just as soon as we found that, we made longer connections and gave greater clearance in the brickwork, so that they could bend, and we had no further trouble.

Mr. LaForge.—I do not know that I entirely understand Mr. Henning and his method of getting the measurement of the expansion of a boiler. It seems to me, though, that rods going through would be likely to expand and contract as well as the boiler itself. It would be very difficult to get the measurements with any sort of accuracy.

Mr. Henning.—I happened to take one rod that had been divided by inches, and I inserted this same rod at different points, front and back, without leaving it in any length of time so as to produce considerable expansion, and then I measured the distance I inserted this rod from some boards set vertically and independently of the boiler setting.

Mr. William Garrett.—No matter what the method was by which the gentleman took the measurement of those boilers so as to know whether the bottom of the boiler was longer than the top, I should think that common sense would tell us that the bot-

tom of the boiler, having more heat under it, would naturally expand more than the top of the boiler, where there is less heat. So I have no doubt that the bottom of the boiler is always longer than the top.

Mr. McBride.—Perhaps it might be well for me to say I measured the boiler on the top of the shell from the end of the sheets where they are attached to the heads. I measured along on the top of the boiler on the bare shell. I took my measurement with a wooden rod, and the expansion was about $\frac{3}{8}$ of an inch.

Mr. Baker.—I was merely going to ask the last speaker whether he thought there was any considerable difference in the actual temperature of the metal at the bottom and at the top of the boiler notwithstanding the greater heat applied to it.

Mr. Boyer.—In reference to the expansion of the metal, probably if we had our "Haswell" or other reference books here we could very quickly determine what the expansion amounts to. I cannot help thinking that this $\frac{3}{8}$ of an inch in 16 or 18 feet is overdrawn. I had occasion to put a pipe under a street for taking liquefied ammonia across—a welded pipe. I wanted to test it, and I laid it on a floor. The pipe was 85 feet long. I put steam pressure on up to 80 pounds, which gave me 312 degrees, and my pipe elongated about $\frac{5}{8}$ of an inch. When you speak about the expansion of a boiler hanging in the lugs, it is not expanding all one way, but it is drawing to three different points—from the end of the boiler to the lugs and from the lugs to the centre. I still think that the working of the boiler on its lugs is but three or four hundredths of an inch. I wish we had here to-day Colonel Haft, of the New York & New Haven RR. Company, to give us a description of his boiler settings, where he is placing between his grate-bar and boiler 48 inches.

The President.—That was for burning sparks, I believe.

Mr. Boyer.—Yes, sir; he is burning locomotive sparks. When they take the locomotives to the round-house and open the front connection doors, they find collected on the spark-arrester (wire screen) a large quantity of small particles of coal unconsumed, and it is this collection which Colonel Haft is using in his furnaces for steam generating. If I were installing a new battery of plain horizontal tubular pattern of boilers, I would build a grate-bar 9 feet long and 48 inches clearance between the grate and the shell of the boiler. I should burn soft coal and coke, the coal on front part (6 feet) of the grate-bar, and have a thin fire of hot coals on

the back part of the grate which would admit of air passing through, and in so doing it would become heated to a high degree (from 1,200 to 1,800 degrees Fahr.). This, when coming in contact with the distilled gases from the coal, would cause complete (or nearly so) combustion in the combustion chamber back of the bridge wall and in the flues of the boiler. In my own boilers we are using this system, confined as we are to a 6-foot grate-bar and a 34-inch clearance between the grate and boiler, and we get a working result with Pocahontas or New River (soft Southern) coal of $10\frac{4}{10}$ pounds of water to a pound of combustible.

*Mr. Orosco C. Woolson.**—I feel called upon to say that I was morally certain that a bold philippic on the subject of boiler setting would arouse some latent heat, and I strongly suspect that had Demosthenes turned his energies loose on boiler abuses instead of on the abuses of King Philip, he would have been torn to pieces by the populace, but as history records nothing of that kind, I think it fair to assume that the Grecian orator confined himself to matters of less importance, wherein the mass of the people felt that he was right, and therefore did not annihilate him or even declare him "inconsistent," through incorrectly interpreting his meaning, nor was he "hung on a fence," or much less was it suggested "to march him around the country on stilts," but rather he was cheered for his boldness and courage in telling some wholesome truths.

I am particularly pleased to hear from Mr. Hugo, for his remarks take me back just twenty-six years, at a time that I set several boilers in Ohio and Illinois in just the manner he describes.

The extended lower front half of shell he mentions, having a band of ½" x 1" iron riveted on, found a lip to catch over a semicircular flange on the inside of the front, fixing the boiler securely forward, the back end resting on a concave roller, as Mr. Hugo describes.

There are several good features attached to this style of carrying a boiler in brickwork, but, for the varying conditions in which boilers are placed and operated, I regard the system presented in my paper as much superior, taking all things into account.

The matter of expansion and contraction in boilers has received

* Author's closure, under the Rules.

considerable attention, and I cannot refrain from saying I do not believe any one can sit down and accurately determine just the amount of movement (we will not call it expansion) to which a boiler of any size will be subject in the brickwork. I recall one case in a battery of five tube boilers which I put up in Chicago, supported in the manner described by Mr. Hugo, in which the back head had a movement of nearly three-quarters of an inch. The shells of these boilers were 18 feet long.

Now, I do not say that this movement was due to the expansion of the shells or to the expansion of the brickwork, or to both, working, possibly, in opposite directions, but I feel that we confine ourselves too much to simple expansion or contraction, due to metal so many feet long and a temperature of so many degrees, and conclude that that is all there is in it.

Replying to Mr. Barnaby, I can only repeat what I before expressed, that I do not believe it possible for any one correctly to determine just to what extent a boiler will move.

That one boiler of the same size as another is quite likely to have a more or less movement and that all boilers move, some more and some less, there is no question, and I would not value any set of experiments which apparently proved there was no expansion, not to say movement.

The particular movement in any one boiler is constant under like conditions, but the movement of the brickwork is not constant, and for various reasons becomes, in many cases, much more than the boiler.

I have found *this* a very common condition; say, for example, the setting is new and the boiler fired up for the first time, being such a one as described in my philippic, where the boiler is thoroughly anchored in the mason work, so that the moment the shell begins to squirm and expand to adjust itself it crowds the mason work and shortly cracks it, and in this condition it remains for the time, while dirt, dust, and bits of cement find their way into the cracks, thereby preventing the brickwork from returning to its original position when the setting is cooled down.

The logical and potent result of this is that, when fired up again, the boiler goes through the same movement as before; but the brickwork has got a start already, and this second boosting aggravates the matter, and the cracks increase in size and quite possibly in number, until such time arrives when the whole setting is so free and loose from the shell as to be incapable of further influence

from it, and becomes simply a poorly supported casing, which finally falls to pieces, one and two bricks at a time, in the natural course of events, till we conclude to give it a thorough repair or take it down altogether, charging it up, of course, to expense account and innocently congratulate ourselves that it is all regular and must be expected in steam-boiler plants everywhere, and possibly shaking hands with ourselves to think we managed to keep running so long without experiencing more serious trouble.

In replying to the remarks of Mr. Boyer, which will apply to several others as well, I am forcibly reminded of the thoughts that came to me when I concluded to write my paper, to wit: There will always be, perhaps, a certain amount of antagonism between the fire-tube and the water-tube boiler advocates, and I am free to say I expected to be classed with the fire-tube fraternity; yet a careful perusal of my paper will not justify such an impression.

There are good features to be found in both styles of boilers, and my purpose was not to create discussion on any points except such as pertain to the horizontal fire-tube problem, and in no instance did I speak of the water-tube boiler as "pipe" boilers. Yet if Mr. Boyer thinks by supporting a fire-tube boiler somewhat after the manner of the water-tube style, and assumes by so doing that such boiler is capable of "marching over the country," then my reply is: "We are now on the march."

Mr. Boyer's remark that he is an "operator of boilers, and not a builder of boilers," prompts me to say that I have been both builder and operator during the past twenty-eight years, and such opinions as I have formed about the manufacturing, shipping, erecting, setting, and handling of boilers have been based entirely on practical experience. If such had not been the case, I confess I should not have had the courage that Mr. McBride credits me with.

Mr. McBride evidently is not a fire-tube boiler man except from force of circumstances, therefore we shall have no opportunity to argue; but, taking his own statement of expense with his boilers during the past twenty years, I am prompted to say to him that what he needs is more "refinement" and less repairs.

One of the objections to resting the shell of a boiler on a concave roller at the rear, or on a leg, is just what Mr. McBride mentions.

Under certain conditions of firing, this construction, continually enveloped in carbonic acid, deteriorates rapidly. Still, if Mr. Mc-

Bride had done just the reverse and had employed a very small hard-burned fire-brick such as are used in steel works he would have had better results than with such large slabs of silicious material, yet I think, under the circumstances, he did well to adopt other means to support his boiler. At the same time I cannot prevent my thoughts from reverting to the last two lines of the second paragraph of my paper.

To reply fully to the excellent remarks of Mr. Bryan would occupy too much of the time of the Society, but by turning to the cut shown of the boilers he refers to as his "most recent practice" I notice he has adopted several features that I thought were good many years ago, but which, as mentioned in my paper, I have now abandoned for something I consider better.

By reference to the cut of my wood furnace boiler, which was illustrated in the *American Machinist*, May 14, 1891, it will be seen that I hung the boiler by links to cross-beams resting on iron uprights, both fore and aft.

The cross *I* beams were turned down flat, which reduced the height required, yet they were capable of doing this by reason of their particular close support, thus requiring but a single beam.

The first paragraph on page 783 of my paper answers, I think, some features of Mr. Bryan's remarks.

I believe the circular return at the rear, shown by Mr. Bryan, has its good features, but it has also a greater number of objectionable features, and I therefore abandoned it.

The dropped chamber at the rear I believe has no practical objections to it in ninety-nine cases out of a hundred; therefore I adopt it.

Of the circular return shown in Mr. Bryan's cut and that in my cut of 1891, I prefer mine for this practical reason: In his design he places his cleaning-out door entirely below the shell of the boiler. This door, if for cleaning out solely, should be placed somewhere on the side of the setting if possible to do so. Where it is not possible a pocket should be located in the paving back of the bridge wall and reached by a tunnel from the rear.

Where there is no drop chamber at the rear there should always be a door of liberal size up opposite the tubes to enable a man to easily examine his boiler head, even when it may be under steam, and for that reason I placed the door in the 1891 cut up high and left out the circular arch above, but I provided for movement of the boiler, as will be seen by a glance at this old cut.

The practice of affording ample opportunity to get at the shell of a boiler for inspection, no less than for repairs, is imperative with me, for I have been obliged to crawl around under boilers and lie on my back on a long inclined paved bottom, with my heels dug into such crevices as could be found, to enable me to get into some particular spot with a hammer or a chisel and a smoky lamp, quite enough for a life-time, and therefore, if any of the tubes in the rear head, over Mr. Bryan's circular return, need expanding I should not care to double myself up on that curve to do the work, no matter what particular tube it might be that needed attention.

The protecting sleeves shown on my blow-off pipe are preferable to the use of brick for the following reasons: They are made of a more refractory material than ordinary fire-brick, and particularly bull-nose fire-brick, such as Mr. Bryan shows, and as employed for my purpose of protecting the pipe, they expose fewer joints than is possible with a built-up sleeve such as he shows. Still, what is more important, my sleeves being strung on the pipe and held up to place with the collar at the bottom, there is no liability of any of the joints opening from settling of the earth or paving under the boiler, as would be quite likely to occur in Mr. Bryan's plan. In fact, with my sleeves there need be no fire-clay joint exposed at all, because these sleeves being male and female, it requires only a small amount of clay paste in each joint, and the simplest method of making up the whole length of pipe covering is to slip the several sleeves on to the pipe when the blow-off is ready to be screwed into the shell. And you will notice that these sleeves all slip down till the iron collar at the bottom rests on the elbow, thus leaving sufficient exposed pipe to get hold of it above the sleeves.

When ready to clay the joints and put the sleeves finally in place it is simply necessary to get a pinch bar under the collar and force them all up and fasten the set screw and the job is done for all time.

I am sorry not to have heard more from Mr. Laforge on this subject of hanging and setting boilers, for I value his opinions greatly because he is constantly having to meet the objections inherent in different styles of boilers and settings.

I beg to thank the members for the courtesies extended to me in this discussion, and particularly to thank Mr. Fawcett for his remarks and to say he leaves me nothing to answer.

DCCLXXXV.*

GINNING AND BALING COTTON, FROM 1798 *TO* 1898.

BY GEO. A. LOWRY, BOSTON, MASS.
(Associate Member of the Society.)

Fig. 195.

Ginning.

In the year 1784 an American vessel arrived in Liverpool with eight bags of cotton, which were seized by the customs officials on the ground that it could not possibly be American cotton; next year there were five more bags exported, six bags in 1786, and one hundred and eight bags in 1787. This was all Sea Island cotton (*i.e.*, long staple cotton), for until 1791, when Whitney invented his cotton gin, upland cotton (*i.e.*, short staple cotton) was practically unknown. This short staple cotton adhered so obstinately to the seed that an operator could clean only one pound per day.

Two years after Whitney's invention of the gin the crop had grown to five million pounds; ten years later, to thirty-five million pounds; and in twenty years it had grown to eighty-five million pounds, while the estimate of the crop last year (that of

Fig. 196.

1897) was five thousand five hundred million pounds. Of this only fifty million pounds is Sea Island cotton, the remainder being upland.

In the year 1791 two operators could produce two pounds of cleaned cotton per day. With the present system of automatic feeders, etc., only two men are required to remove the cotton from the wagon and attend to six gins producing twenty-four thousand pounds of cleaned cotton daily.

Previous to the invention of the Whitney gin a small roller gin (invented in India some centuries ago, and called a "Churka") was used. It consisted of two rollers placed parallel to each other, with a small space between, and revolving in opposite

* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

directions. One of the rollers was smaller than the other, the smaller one being of iron and the larger of wood. The operator turned the machine with one hand, and fed in the seed cotton with the other. Only long staple cotton (which is easily detached from the seed) could be cleaned with this machine, and its output was about three pounds per day. Most of the roller gins of to-day are modifications of this type, the widest departure being that of the McCarthy gin, Fig. 196, which consists of a leather roller and two steel blades, one of the blades being pressed against the roller, while the other blade has a rapid reciprocal movement, and strikes the seeds as they are drawn against the edge of the first blade by the adhesive action of the cotton to the rough surface of the revolving leather roller. This rapid striking movement detaches the seeds from the fibre.

The original Whitney gin consisted of a drum with rows of wire hooks, or teeth, inserted in line around it. As the drum revolved, these teeth passed between a grate, or grid, the bars of which were sufficiently far apart to permit the teeth to pass without touching, but so close that the seed could not pass between. Another grate, wide enough to allow the cleaned seeds to drop through, was mounted to form a hopper for the seed cotton, and hold it against the revolving drum. The revolution of the drum, coupled with the drawing action of the teeth against the cotton in the hopper, caused the cotton also to revolve and form into a roll, thus resulting in continually presenting new material to the teeth, and giving the cleaned seed a chance to drop through the wider grate forming the hopper. As the teeth, or hooks, passed through the roll, they became charged with filaments of cotton, and the seed being held back, either by the surrounding material pressing against it, or by its contact with the forward grate, caused the filaments to be detached from the seed and carried forward by the drum, until they were removed by a brush revolving with greater rapidity in an opposite direction, and in such a manner that the bristles brushed the teeth in the direction in which they were inclined. This removed the filaments of cotton from the drum, and the speed of the brush was sufficient to clear itself by centrifugal action. As will be seen by the accompanying drawing (see Fig. 197), the Whitney brush was four-armed.

Numberless patents have been issued and a few improvements made on the Whitney gin, but the principle remains the

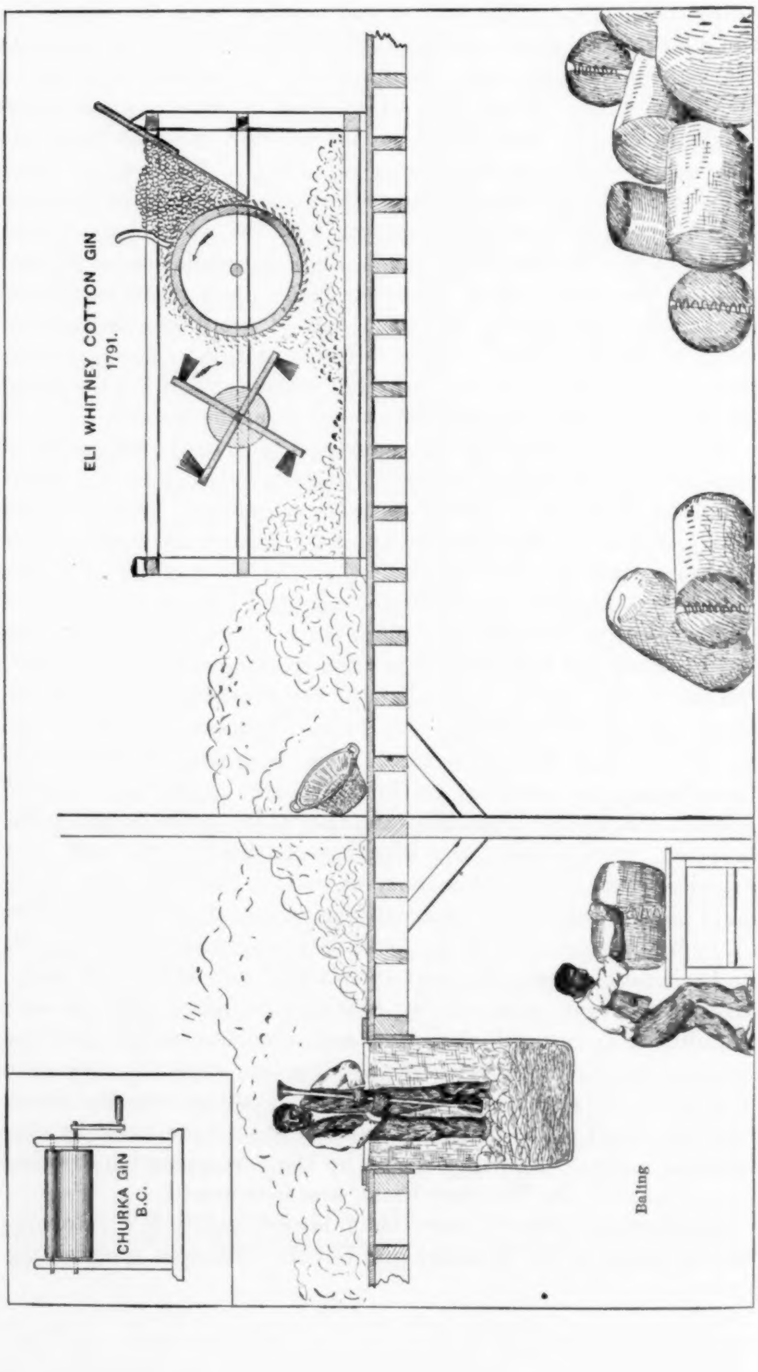
ELI WHITNEY COTTON GIN
1791.
CHURKA GIN
B.C.
Baling
AMERICAN BANK NOTE CO., N.Y.
LOWRY

FIG. 197.

same. Instead of the wire teeth fixed in a drum, we have teeth cut out of a circular metal plate. The brush consists of a drum with rows of bristles inserted lengthwise across it, and with wings on the end to give an air current. Rotatable plates have been placed at the ends of the cotton roll to reduce the friction and assist it in revolving, and perhaps the most important improvement is the mote board,* which regulates the current of air produced by the wings on the brush so nicely that the current is just strong enough to carry off the cleaned cotton, but not enough to carry off the motes, or immature seeds, which thus become separated as wheat is from chaff. The addition of this air current, and the passing of the cotton through flues to a lint room, or condenser, also materially assist in opening up the neps occasionally caused by the films of cotton doubling around the teeth and becoming snarled.

The lint room was merely a large compartment or box fitted with screen ventilators, into which the cotton was blown, the ventilators allowing the air and dust to pass away.

In 1878 a condenser was added and made a part of the gin. This condenser is a revolving screen, and as the cotton is blown against it the air passes through, leaving the lint on the face of the screen in the form of a bat, the air passing out through the bottom and ends of the condenser, and carrying the dust and dirt with it, the screen, as it revolves, constantly presenting new surfaces to the oncoming cotton. A bat roll is placed over the top of the revolving screen and lifts the cotton from it, delivering it into a chute.

Fig. 198 shows the gin with the improved brush and lint room as made in 1848.

Fig. 202 shows the gin and condenser as manufactured at the present day.

The capacity of a roller gin is about four hundred pounds daily. The capacity of the improved Whitney gin is four thousand pounds per day.

A roller gin consumes seventy-one thousand foot-pounds of power for each pound of cleaned cotton, against thirty-five thousand foot-pounds on a Whitney for the same quantity.

The Whitney gin has, unfortunately for itself, become known as the "saw gin," and I will hereafter speak of it by that term.

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* Invented by Eleazer Carver in 1845.

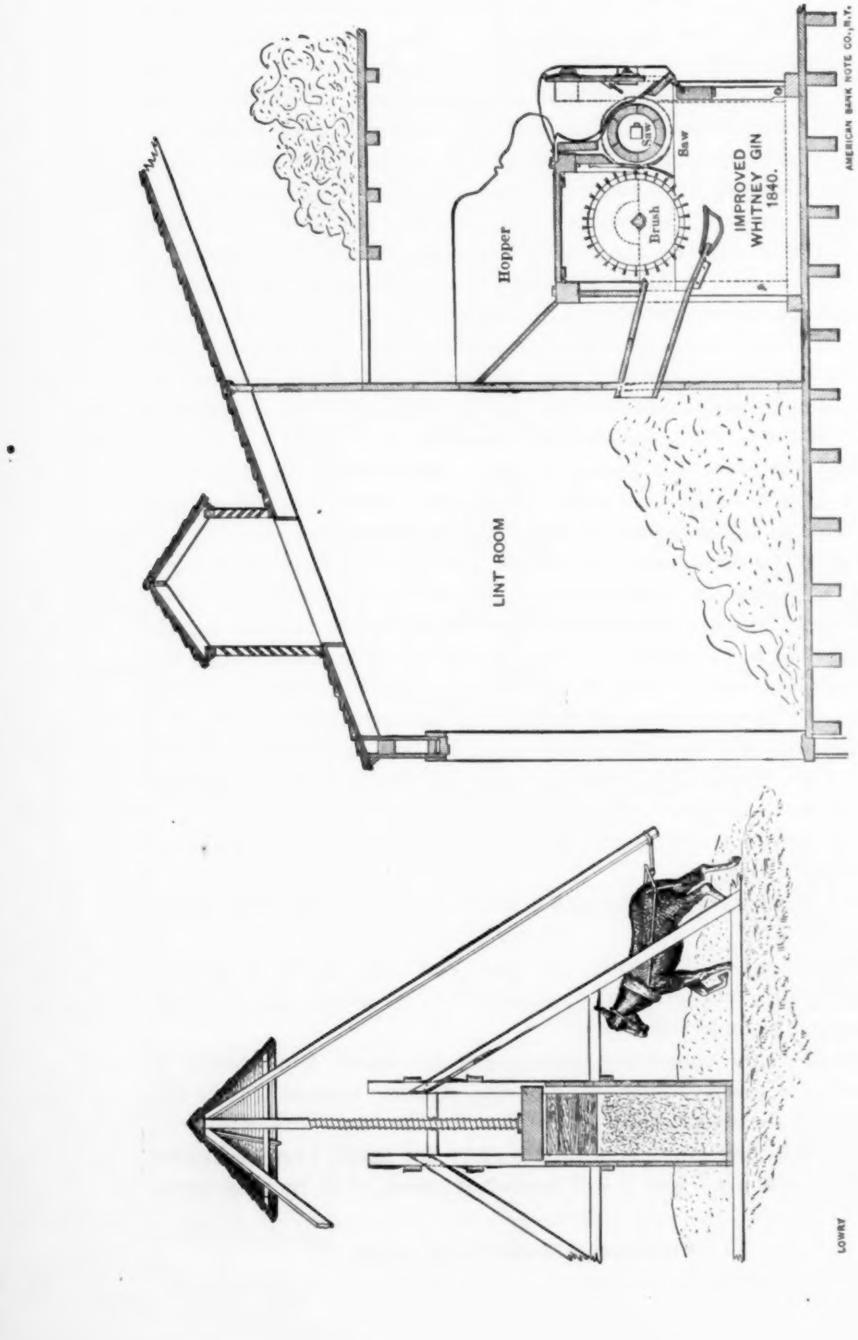

Hopper
Brush
Saw
Saw
IMPROVED
WHITNEY GIN
1840.
LINT ROOM
AMERICAN BANK NOTE CO., N.Y.
LOWRY

Fig. 198.

I say "unfortunately," for the word "saw" has a ripping sound, and has resulted in the general and mistaken belief that this form of machine is particularly injurious to the fibre, while the actual facts are that the saw gin does not hurt the cotton any more than does the roller gin, and neither of these gins will hurt the fibre materially, unless run at too high speed, as the injury to the cotton depends upon the suddenness of its detachment from the seed. Every sample of cotton contains a portion of weak fibres, running all the way from a tensile strength of from forty-six to two hundred and twelve grains (breaking strain), and naturally the weaker fibres suffer the most in ginning. Cotton from saw gins shows a little more neppiness than from roller gins, but the cotton from the latter will be more curled and twisted, and this curling in cotton is very apt to result in neppiness when being carded.

The cotton from saw gins is much cleaner than from roller gins, and opinions for, or against, these machines will depend upon whether most attention is shown to neppiness or cleanness. If the teeth in a saw gin are made smooth and well rounded at the root, and curved so that they will enter the cotton at the right angle, they will not injure it unless run at a very high speed, but it unfortunately happens that most of the ginning in this country is done by custom ginners, who get so much per bale for their work, and whose interest lies more in the quantity they turn out than in the condition of the cotton after it is ginned, and, as a rule, they run their gins at a very injurious speed. They would do the same with the roller gins, however, and the results obtained would be equally as bad.

A number of tests made carefully on cotton obtained from saw and roller gins show the following results, viz.:

2.5 per cent. degree of neppiness from roller gins.

2.7 per cent. degree of neppiness from saw gins.

Cleanness—

0.8 per cent. of leaf from roller gins.

0.00 per cent. of leaf from saw gins.

1.2 per cent. of crushed seed from saw gins.

1.5 per cent. of crushed seed from roller gins.

Seven samples taken from a hank of yarn made from roller-ginned cotton showed an average deterioration of 1.4 per cent., while eight samples of yarn made from saw-ginned cotton showed an average deterioration of 1.7 per cent.

If "the man who causes two blades of grass to grow where one grew before is a benefactor to his race," how much more so is the man who causes 25,000,000 acres of land to be tilled where one was tilled before?

This Whitney has done for the South. How has the South shown its appreciation?

Baling.

The world's exports of cotton goods amounted to about

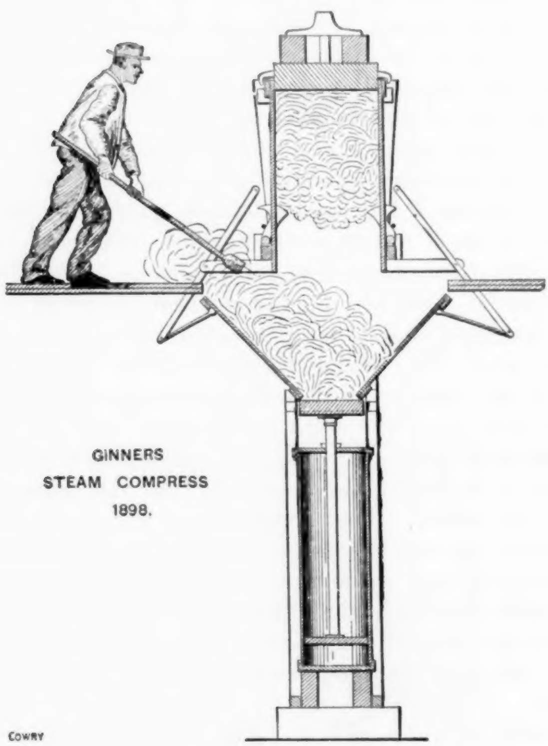


FIG. 199.

$400,000,000 in the year 1896. Of this, 95 per cent. is manufactured in Europe, and only 5 per cent. in the United States, and only one-tenth of the latter amount is manufactured in the South where the cotton is grown.

This has necessitated shipping the greater part of the crop

many thousands of miles, and a tremendous outlay for freight and bagging. To mitigate this, many millions have been expended in order to reduce the cotton to a density which will give ships and cars their full capacity of tonnage, which is about 40 pounds to each cubic foot of space (if the package is round it would require 47 pounds to the cubic foot).

There are about $70,000,000 now invested in the large compresses at central points, and about $20,000,000 in planters' presses.

The first system of baling cotton, used in the years 1780 to 1810, was that of tramping and mauling it into round bags about nine feet long and holding about 300 pounds, as shown in Fig. 195. This compressed the cotton to about five pounds per cubic foot. Then was introduced the old-fashioned wooden screw press, shown in Fig. 198, which compressed to a density of about eight pounds. Between the years 1840 and 1860 were introduced the power screw presses, and about 1870 the steam press as shown in Fig. 199. The latter two forms of press are those most in use at the present time, and press cotton to about 12 pounds per cubic foot. The best results from these give but one-fourth of a load. In 1845 was introduced the Tyler hydraulic compress, and in 1874 the Morse steam compresses were introduced for the purpose of recompressing the bales put up by the planters and ginners. The immense outlay for such plants prevented their erection at other than central points and seaports, the cost for the compress alone being from $40,000 to $60,000, and requiring a steam capacity of three 150 horse-power boilers. (The latest form of these is shown in Fig. 200.) The pressure exerted by these gigantic machines is from 5,000,000 to 6,000,000 pounds on each bale, or about 2,800 pounds per square inch, the bale while under the press being reduced to about 60 pounds density to the cubic foot; but so far they have been unable to keep it from reexpanding when released from the press, and the average obtained is only 22½ pounds per cubic foot. Very few bales "dock" at Liverpool with a greater density than 20 pounds per cubic foot. In reëxpanding, the bales assume a turtle-back shape, which prevents their being stored economically and necessitates "jack-screwing" them into place when stowed aboardship. The regular charges at New Orleans for recompressing, screwing, etc., are $2.04 per bale, and the job when finished is a mighty poor one.

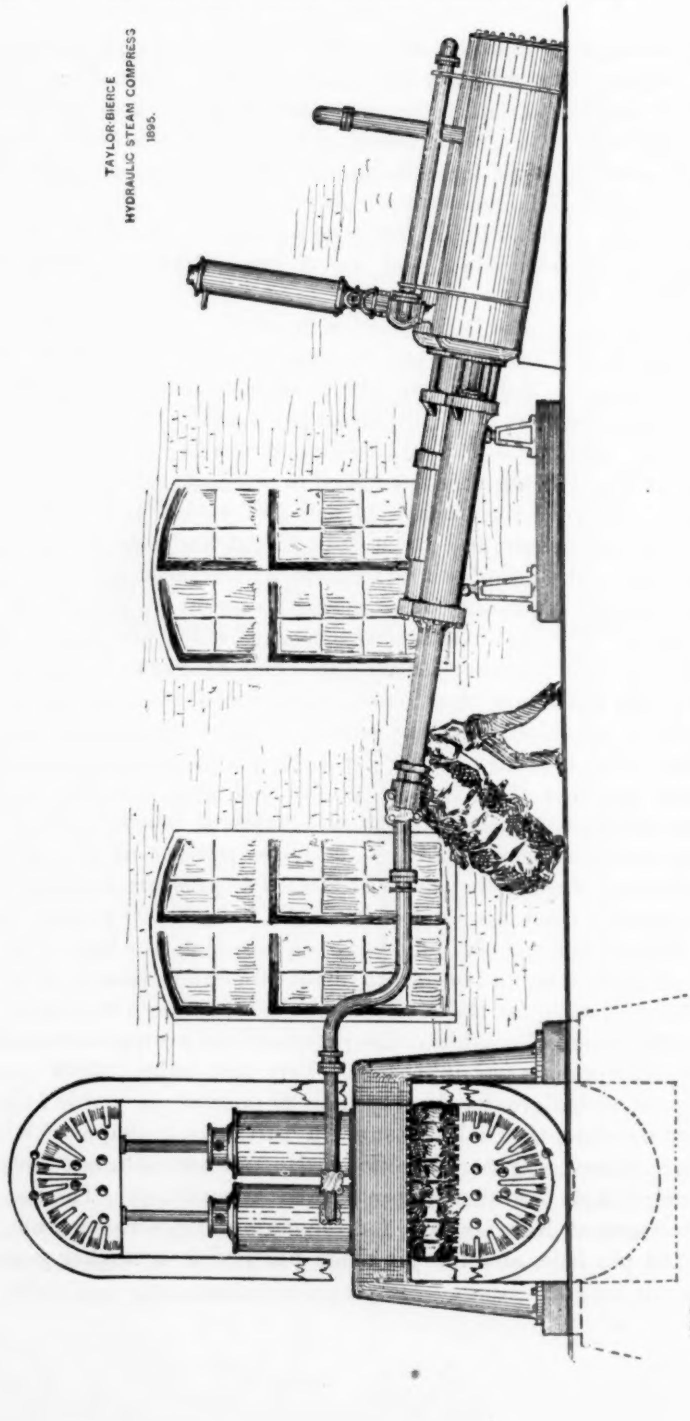


Fig. 200.

The American Cotton Company, by their revival of the cylindrical baling machine, have done a great deal to stir up the planters and ginners to the fact that their present methods must be improved or abandoned. This cylindrical bale (which consists in winding a bat of cotton around a core and putting pressure on the layers as they are wound by means of receding drums in sliding boxes held elastically against them) was first made by the E Carver Company at East Bridgewater, Massachusetts, in 1844, for J. E. Carver and W. F. Pratt. They spent $2,400 on the machine, but abandoned it because the mills objected to the difficulty of unwinding, and the felted condition of the cotton at the centre of the bale caused by the layers creeping on each other, accumulating and concentrating the pressure towards the centre. Each layer was necessarily less dense than the layer beneath, which it assisted in compressing, and the bale could only have an average (instead of a uniform) density, which was in inverse ratio to its diameter. (This peculiarity was strikingly exemplified some time since at the Ordnance Department at Washington when they tried to wind a steel gun core with wire, the result being a sufficient accumulation of pressure towards the centre to crush the core.) Patents were issued in 1847 to Mead, and in 1848 to North, for machines of this type, but until the improvements by Bessonette, in 1893, no material progress was made in bringing it into practical use. There are now thirty-five plants established, which, last season, put up sixty thousand bales of cotton, compressed to a density of about 30 pounds per cubic foot, the pressure exerted being one thousand pounds to the square inch. (It must be remembered that about 17 per cent. is lost in stowing cylindrical packages.)

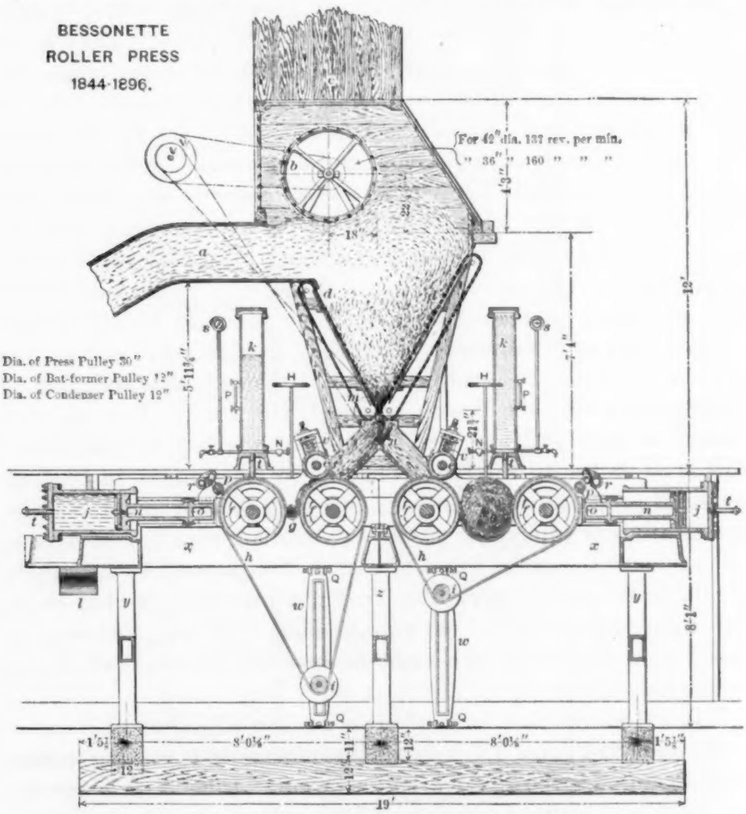
Fig. 201 shows this form of press as now constructed.

Between 1840 and 1850 two other forms of pressing cotton were invented, one of which had a circular tube with a revolving head containing a number of cone rollers placed parallel to each other, with a narrow space between. As the head containing the rollers revolved, the cotton was intended to feed between them; but the inventor failed to notice that as one side of the roller rotated inwardly, the other side of it must necessarily rotate outwardly, thus preventing any drawing in action on the cotton. As several other inventors have, within a few years, tried the same scheme with like results, the prior

inventor (if still alive) need not feel humiliated at his want of foresight.

The other form referred to was twisting the cotton into a thick rope and coiling it on a spindle ; this needs no comment.

During the past ten years efforts have been made by several inventors to pass cotton between metal rollers held tightly together, and have the rolls move reciprocally over the receiv-



Section of Double Press, Bat-former and Condenser.

a—Lint flue.	*h-h*—Baling belts.	*n-n*—Piston rod.
b—Condenser drum.	*i-i*—Belt idler.	*p-p-r-r*—Tension rolls.
c—Dust flue.	*j-j*—Hydraulic cylinders.	*s-s*—Pressure gauges.
d-d—Bat-former aprons.	*k-k*—Pressure column.	*u*—Swinging chute.
e-e—Compression rolls.	*l*—Press pulley.	*w-w*—Guides for belt idler
f-f-f-f—Baling rolls.	*m*—Bat-former pulley.	*N-N*—Pressure regulators.
g-g—Cores.		

LOWRY AMERICAN BANK NOTE CO., N.Y.

Fig. 201.

ing box, or the receiving box move reciprocally under the rolls, thus folding the cotton into layers; the box in either case having a screw or hydraulic mechanism attached thereto to compress the layers of cotton. The greatest difficulty found with this style of machine has been to pass cotton between metal rollers without injury to the fibre.

The latest distinct form of press is that shown in Fig. 202. This press is somewhat of a mechanical problem, and the attention of the Society, with a view to solving the principle involved, is particularly requested, as its application to a useful art is entirely new, and possibly capable of being much extended. The press consists of an inner sleeve 19 inches inside diameter at the top, and drawn in to 18 inches in the first 12 inches of length. This sleeve has a collar, or flange, and revolves on anti-friction bearings, on the shoulders of the stationary outer casing. Bolted to this outer casing is a slotted cap plate. The slots are one-ha'f inch wide, and run radially from within an inch of the centre to the outer diameter of the sleeve. Eight slots are used on the present machine. On the inner sleeve is mounted a spur gear, by which the sleeve is made to revolve, and a drawn steel tube, to carry the bag for the reception of the cotton, is attached to the sleeve by a flange. In operation the sleeve is first filled with cotton, sufficiently tight to give some pressure against the cap plate; the cotton, as it comes from the gins and condenser, falls on the cap plate, and some of the fibres become engaged with the cotton moving underneath the slots. These fibres draw in other fibres, with which they are interlaced, and in this way the whole body of cotton on the cap plate is soon engaged and kept moving towards the slots. As the cotton is drawn around the lips of the slots the upward pressure of the material in the sleeve squeezes out the air and compresses the fibres, and there is no opportunity for reëxpansion; this continuous introduction of new material forces downward the material already in the chamber. The narrowing of the diameter, or otherwise the choke in the sleeve, together with the length of the tube, gives the resistance which regulates the density of the bale. To give a greater or lesser density the choke is increased or decreased, and the tube lengthened or shortened. With this machine, and an exertion of 25 horse-power. cotton has been compressed to a density of 86 pounds per cubic foot. (Oak is but 54 pounds to the cubic foot.) But in practice the bales are only made to

a density of 50 pounds per cubic foot, as that is sufficient for the full utilization of any shipping space. By taking in a very thin bat of cotton, only a small amount of pressure is needed to

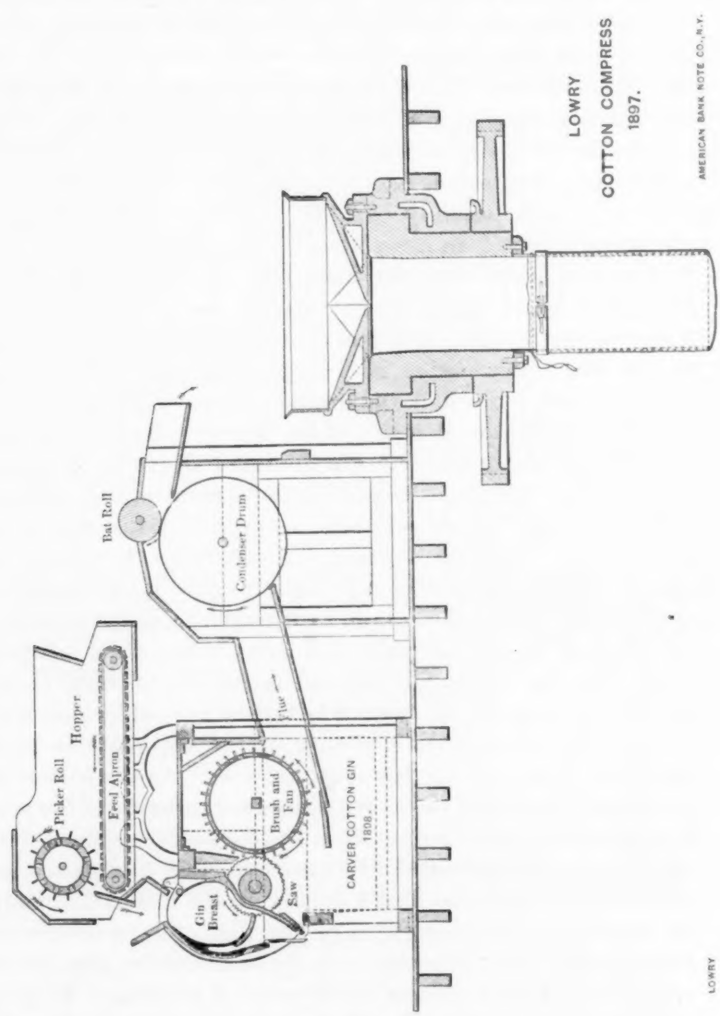


Fig. 202.

compress it to the required density; the large compresses find it necessary to obtain a pressure of 2,800 pounds to the square inch to compress a full-sized bale to 22 pounds density, and the

American Cotton Company, with a thicker bat, require 1,000 pounds pressure to obtain a density of 30 pounds, while with this thin bat only 60 pounds pressure to the square inch is required to compress the cotton to a density of 50 pounds to the cubic foot.

At the inception of this machine it was deemed impossible, by those consulted, to obtain enough frictional resistance in a construction such as this on yielding material like cotton, to obtain any amount of density, and the first machine was made with 3 inches of choke in 24 inches of length, the chamber being 16 inches diameter at the bottom and 19 at the top. The first two bales came through, but the third had become so very solid that it could not be moved, and it finally pushed off the cap plate, stripping the thread from the bolts.

I am of the opinion that the resistance is created by the cotton forming an arch, or bridge, using the sides of the sleeve as an abutment.

The machines of this type in operation have a capacity of about 2,000 pounds per hour, running at a speed of 14 revolutions per minute, and make bales built up of spiral layers, which, when opened, spring apart, thus saving much arduous labor at the mills, and facilitating the mixing of the cotton.

As will be seen from the construction of this machine, it is inexpensive to build, and will easily come within the reach of the planters and ginners, thus doing away with the recompressing and rehandling of cotton now made necessary by present methods, and will fully utilize the carrying capacity of ships and cars—making the saving on a crop as large as that of last season of over $40,000,000.

I beg to acknowledge my indebtedness to Dr. Forbes Watson, J. E. Carver, *Silliman's Journal*, and the *Manufacturers' Record* for much of the preceding information.

DISCUSSION.

Mr. S. N. Bourne.—The ease in handling, opening, and cleaning the sack is a great advantage. The sack can be turned back to expose a part or the whole of the hole for inspection, and can be taken off intact and used or sold again.

NOTE.—The revolving of the cap plate with a stationary sleeve gives like results.

In regard to mixing—

It is very desirable to put into a mixing at one time the cotton from several different bales, and is much to be preferred to the present custom of putting one bale through, then another, and so on, one bale after another. You can readily see that this cotton which lies before us is in a very convenient form for a mixing of this sort.

It seems to me there is a great future in this bale.

DCCLXXXVI.*

EXTENSION OF THE STANDARD UNIFORM METHODS OF CONDUCTING AND REPORTING STEAM-ENGINE TESTS.

BY BRYAN DONKIN, LONDON, ENGLAND.

(Member of the Society.)

THIS subject has had considerable attention in the United States for many years, and valuable work has been done there, more so than in other countries. The writer considers that it is very desirable, and that the time is now ripe for the further discussion of this important matter, and with this object he makes the following suggestions.

More uniformity in different countries could doubtless be obtained in the future by the adoption of such standard methods and by more combined action. Regulations of this kind would add to the comfort and ease of comparing steam-engine results of very different types in the United States and Europe. The American Society of Mechanical Engineers has for some years taken the lead in an excellent and practical way.

Steam Boilers, Locomotive and Pumping Engines.—This Society has formulated methods and instructions to be used for testing, not only steam boilers, but also locomotive and water-pumping engines. This has raised the Society in the estimation of the engineering world wherever English is spoken. In France and Germany, however, little or nothing is known of the useful work which has been carried on, and steps should therefore, in the writer's opinion, be taken to make such methods more largely appreciated.

Marine and Factory Engines, etc.—Similar standard methods of conducting and reporting these experiments should, he suggests, be extended not only to the important branch of marine steam engines, but also to factory, mill, and agricultural engines, and quick-running steam motors for electrical work.

* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

Rotary Engines.—Some notes might also be added to include the new types of steam road carriages and rotary fixed engines, since the efforts hitherto made to standardize trials relate chiefly to the reciprocating type of engine. At the same time, all the existing reports of your committees might perhaps be remodelled and made up to date.

Gas and Oil Motors.—It would also be well that a committee should be appointed by the Society not only to take into consideration the above questions, but also to standardize a uniform method of testing and reporting on gas and oil engines. These extremely economical motors give, as is well known, a very much greater heat efficiency than steam engines. They must, therefore, have a great future before them, and the sooner such methods of trial are published, the better for those who make the tests and those who have to compare them.

Blank Forms.—With regard to the blank forms for the different types of steam engines, the writer is of opinion that it would be better, and likely to cause less confusion, if they were kept quite separate and distinct. There should, he thinks, be different instructions for testing, first, land fixed engines; second, locomotive engines; third, marine engines; and fourth, water-pumping engines. Any engineer, even if not a member of the Society, should be in a position to purchase these blank sheets separately for his immediate use. One set should also be drawn up for steam boilers, and thus there might be in all five pamphlets, each embodying complete instructions. These five pamphlets could always be on sale at a moderate price for engineers, students, and others, and ready for any test. It would be best to have them printed on strong paper, in small book-form, pocket size, as reference to the bulky volumes of the *Transactions* is inconvenient, and taking copies of all blank forms very troublesome and liable to error.

Another step, perhaps of equal importance, which the writer begs permission to suggest, is that the Society should have these forms and instructions translated into French and German, and adapted to the metric measurements of those countries. They could then be sent, if desired, to the most suitable institutions and societies in France, and also to those in Germany, Belgium, Russia, Austria, Switzerland, and Italy. If these societies have not already a standard method of making similar

trials, it might be suggested to them to constitute a committee to formulate similar standard methods for use in their own countries. It would be desirable to add that, if possible, the same general order should be adhered to to facilitate comparisons of the different results in different countries. In this way we may, in a few years, hope to see some approach to uniformity in the records of tests in the different engineering centres throughout the world. In England the Council of the Institution of Civil Engineers, London, at the writer's suggestion, has taken the matter up, and the Thermal Efficiencies Committee (of which he is a member) will shortly issue their full report. Appendix I. (subjoined) gives their preliminary report, published in the spring of 1897.

Another committee has also, at the writer's suggestion, been lately appointed by the council of the same institution, for considering and reporting upon the best set of headings for standardizing steam engine and boiler experimental results. This committee has not yet issued any report nor held any meetings. The conclusion arrived at in the preliminary report of the Thermal Efficiencies Committee is that all steam and heat engine results should be given in thermal units per indicated horse-power and brake horse-power, and not in pounds of steam per indicated horse-power and brake horse-power only.

Dealing with so large a subject, no programme can ever be final, but will require revision every few years, as science advances, and better instruments are invented or brought out.

The writer is very glad to see that Mr. Barrus, of Boston, and others, are advocating similar standards, and also adapting to modern requirements those already published by this Society.

In future, if the English and American standard result sheets for steam engines and boilers could be issued in the same general order, it would help to make the experiments and render comparisons easier.

At present there is no agreement amongst engineers as to the best standard for efficiencies of steam engines, in order to compare the results of any actual steam engines with those of an ideal engine. This difficult question has been discussed by the London Institution of Civil Engineers' Thermal Committee, and their report will be published shortly.

Appendix II. contains a few additional suggestions of less importance than those mentioned above, but upon which discussion by the Society is invited.

APPENDIX I.

PRELIMINARY REPORT OF THE COMMITTEE APPOINTED TO CONSIDER AND REPORT TO THE COUNCIL UPON THE DEFINITION OF A STANDARD OR STANDARDS OF THERMAL EFFICIENCY FOR STEAM ENGINES. (LONDON INST. CIVIL ENGINEERS.)

Your committee beg leave to report that they have now practically come to an agreement on the subject of the reference to them, and that the draft report has been drawn up.

The conclusions to which they have come to are as follows:

(1) That the statement of the economy of a steam engine in terms of pounds of feed-water per indicated horse-power per hour, is undesirable.

(2) That for all purposes, except those of a scientific nature, it is desirable to state the economy of a steam engine in terms of the thermal units required per indicated horse-power per hour (or per minute), and that, if possible, the thermal units required per brake horse-power should also be given.

(3) That for scientific purposes the thermal units that would be required by a perfect steam engine, working under the same conditions as the actual engine, should also be stated.

The proposed method of statement is applicable to engines using superheated steam as well as to those using saturated steam, and the objection to the use of the number of pounds of feed-water, which contain more or less thermal units according to conditions, is obviated, while there is no more practical difficulty in obtaining the thermal units per indicated horse-power per hour than there is in arriving at the pounds of feed-water.

For scientific purposes the difference in the thermal units per indicated horse-power, required by the perfect steam engine and by the actual engine, shows the loss due to imperfections in the actual engine.

A further great advantage of the proposal is that the ambiguous term "efficiency" is not required.

APPENDIX II.

1. *Percentage of Water in Cylinders.*—The best way of representing graphically the percentage of water in the cylinder of any steam engine after cut-off is a subject well worth considering. If possible, it should be on the same base line as the indicator diagram.

2. "*Cards.*"—The word "cards" should, in the writer's opinion, be abandoned in all future reports and discussions on this subject, and the words "indicator diagrams" always substituted for it. In taking diagrams from steam engines no "cards" are or ever have been used.

3. *Steam Engine Indicators, also Gas and Oil Engine Indicators.*—The public should know the opinion of this Society as to the best types to be used in view of the various speeds (from fifty to five hundred revolutions per minute), and the temperatures of saturated or superheated steam or gas in these motors.

4. *Indicator Springs.*—A standard method of testing indicator springs hot in their indicators. Should such be recommended by the committee?

5. *Position of Indicators on Cylinders of Motors.*—Advice should be given and attention paid to the question of placing an indicator, whether on a vertical or a horizontal cylinder. The two ends of a cylinder should never be joined up by pipes. Each end of each cylinder should have its own indicator, and each pipe fixed with as few bends and made as short as possible.

6. *Smoke Scales for Observation of the Degree of Smoke Every Two Minutes during a Ten-hour Test.*—As the question of smoke and its prevention is likely to come with increasing prominence before municipal authorities, the best way of representing smoke by smoke scales, and standardizing the observations made on it, should, the writer thinks, be dealt with by a committee. The best method hitherto proposed is probably that suggested by Professor Ringelmann with five standard smoke scales, and published in November last in the *Engineering News.*

7. *Power Required for Driving the Engines Themselves.*—When engines are tested, whether using steam, gas, or oil, they should, whenever possible, be indicated when driving themselves only, and this information should be added in all tests.

8. *Leakage.*—Pistons and valves should be tested for leakage of steam or steam and water, wherever possible.

9. *Temperature of Cylinder Walls.*—The temperature of the cast-iron cylinder and cover walls should be more often taken in scientific tests, with the best electrical instruments now available. The paper by Professors Callander and Nicholson * may be referred to as the best on this subject. The temperature of cylinder walls is of great importance, as having a large influence on the condensation of steam.

10. *Steam Jackets.*—Whenever any parts of cylinders or receivers are jacketed with steam, a small pressure gauge, previously checked, should be fixed on each jacket, to determine the actual pressure of steam. A small tell-tale quarter-inch cock, opening into the engine-house, should also be provided on the same gauge fittings, to enable the engineer to see whether air, steam, or water comes out when the cock is turned on. In important tests such cocks should be fixed at the lowest and highest parts of each steam jacket.

NOTE BY THE PUBLICATION COMMITTEE.—The ground covered by Mr. Donkin's paper was so similar to that treated by Mr. Geo. H. Barrus, in his paper presented at the same meeting entitled "Plea for a Standard Method of Conducting Engine Tests," that the two papers were discussed in connection with each other. Readers and students are therefore referred also to the discussion of that latter paper, which will be found as paper No. 781 at page 713 of this current volume of *Transactions.*

DISCUSSION.

Mr. William Wallace Christie.—I am heartily in favor of Mr. Donkin's suggestions. His plan of using blank forms in pocketbook size is very good.

In making tests of steam engines I have found a great variety of proportionate results when measuring the power to move an engine alone, and it seems to me that it would be very advisable to include it in the new tabulation.

The boiler pressure, and admission pressure of steam to cylinder as well as M. E. P., should be noted.

We hear so much about low coal consumption per engine indicated horse-power along with close figuring. Should the economy of engines be given in thermal units per net horse-power, that is, total indicated horse-power less horse-power required to run engine

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* Read before London Inst. Civil Engineers this winter.

alone, some tests might change places and some types of engines now in the first row might be given seats further back.

It would be very much appreciated by all engineers if there could be such a standardizing of tests, etc., as is suggested by the writer of this paper, and also by Mr. G. H. Barrus' paper presented at this meeting.

Prof. R. C. Carpenter.—The paper by Mr. Bryan Donkin, of London, England, calls attention to the desirability of adopting a standard method of engine testing which shall be used by engineers both in this country and in England. I think that all the members of the American Society of Mechanical Engineers would be pleased to see a uniform method employed by all the English-speaking people. They already employ the same system of weights and measures, and it does not seem to me that there should be any very great difficulty in agreeing on a common basis for conducting engine trials.

In Appendix I. to Mr. Donkin's report attention is called to the desirability of reporting results in thermal units instead of in pounds of steam. Professor Aldrich has already called the attention of the Society to the desirability of adopting the thermal unit as a standard, and consequently the matter has been fully discussed by the Society. There is no question but that the thermal unit is a better standard than the weight of water or coal per unit of work performed, but it should also be borne in mind that the value of the thermal unit increases with an increase in absolute temperature, and hence it cannot form a standard unqualified by existing conditions. It also strikes the writer that the old standards of weight should be retained, and not replaced entirely by the newer and more scientific one relating to the thermal value. I think that room can be found in the reports for expressing results in terms of several standards.

Appendix II. of the paper calls attention to some desirable methods in connection with engine tests, regarding which the writer desires to refer to only those under the numbers 1, 4, and 10.

No. 1.—The percentage of water in cylinders is shown graphically in a very accurate manner during the expansion period, by the construction of a saturation curve for the same weight of steam as employed in the engine.

The writer has already called the attention of the Society to the advantages of this curve (see vol. xv., page 904, of the *Transactions*) for determining the quality of the steam during expan-

sion, and also to the fact that by its use the heat interchanges may be computed very easily and with a high degree of accuracy.

Regarding the method of testing indicator springs, the writer has used with great satisfaction for several years past a simple form of apparatus, which is shown in the paper presented before the Society in 1893.* The apparatus consists of a chamber into which steam of any pressure can be supplied. This chamber is connected with a small piston accurately standardized, supported by a stirrup, which is suspended in its turn from the short end of a scale beam resting on knife edges. The piston is kept in rotation without affecting in any way the pressure acting against it, and an attachment can be put on by means of which the drum is given the same alternate swinging motion as in use. By this device we have found it possible to calibrate the indicator springs very quickly and delicately under conditions which are similar to those in actual use. Tests made with the indicator springs, cold and hot, show that considerable difference is found in the results, and that consequently tests of the indicator springs when cold should not be given any considerable weight. Before adopting this apparatus indicator springs were tested in Sibley College by comparison with a mercury column. The results of such a calibration usually indicated irregular extensions of the springs with constant increments of load, and as similar irregular results have been published in connection with the use of the mercury column in the Navy Department for this purpose, I presume such experience is common. A later investigation showed that the irregularity was due to a wave-like motion of the mercury in the column, rather than to any irregularity in the elasticity of the spring. When the mercury column had an electrical connection which made an automatic record, the irregularity seemed to be magnified. With the simple apparatus described and illustrated in the above-mentioned paper no difficulty whatever has been experienced in obtaining regular increments of load, which result, I believe, must happen in every case with a perfect spring which is not strained beyond its elastic limit.

The writer is also of opinion that steam gauges are more conveniently standardized by the use of a similar apparatus than of the mercury column. The mercury column is very accurate when

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* Constants for correcting indicator springs which have been calibrated cold. *Transactions* A. S. M. E., vol. xv, p. 454, paper No. 524.

pure mercury is used and when it is handled with skill, but mercury is a material which readily dissolves many other metals, and much of that sold in the arts will be found to have a specific gravity considerably less than that of pure mercury. The probability, then, of making errors with a mercury column is greater than with the use of standard weights supported on a rotating piston.

Regarding the temperature of the cylinder walls, the writer is not fully satisfied that the matter is of the importance which Mr. Donkin seems inclined to credit; that is, it seems to me that all heat interchanges of importance may be computed by methods similar to that employed in Hirn's analysis, or by the use of the saturation curve rather more accurately than from the temperature of the walls.

Various methods of determining the temperature of the cylinder walls have been investigated by a number of graduate students taking courses in Sibley College, in some cases with fairly satisfactory results. The following investigations have been conducted:

Mr. W. W. Churchill, in 1889, attempted to determine the temperature of the cylinder walls by balancing the electrical resistance of two circuits, using a telephone to determine when the resistances were balanced.

Mr. Robert Hale, in 1893, applied the method used by Professor Hall, of Cambridge, in which thermopiles were employed in the cylinder, the temperature being measured by a thermometer in an external vessel, so arranged that the temperature in the cylinder would equal that in the external vessel when a galvanometer in circuit registered zero. A similar arrangement seems to have been used by Eugene Peclét about 1860, and is described in vol. i. of *Traite de la Chaleur*.

No practical results were obtained from either of these investigations. In 1894 Mr. J. J. McComber devised a photographic apparatus which should be connected to a thermopile in such a manner as to indicate the change of temperature by change in the electrical current produced by the thermopile. Mr. E. T. Adams perfected this method, obtaining in one case the accompanying photograph, Fig. 203, of which the ordinates are proportional to the change in temperature, the abscissa to the travel of the piston.*

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* Reproduced from page 446, vol. xvi., of the *Transactions*, where it appears as Fig. 139 of Paper 627, by John H. Barr, "Experiments on a System of Governing by Compression."

Although this method gave occasionally good results, it was found very difficult to construct a thermopile which would be electrically insulated and at the same time not be insulated against heat, and this difficulty seems almost impossible to overcome at the present time.

Messrs. Barnes and Zimmerman, later Messrs. McGowan and Bentley, have used another method which has proved to be much more certain and practical in its nature. In these cases a constant current of electricity of small intensity was passed through

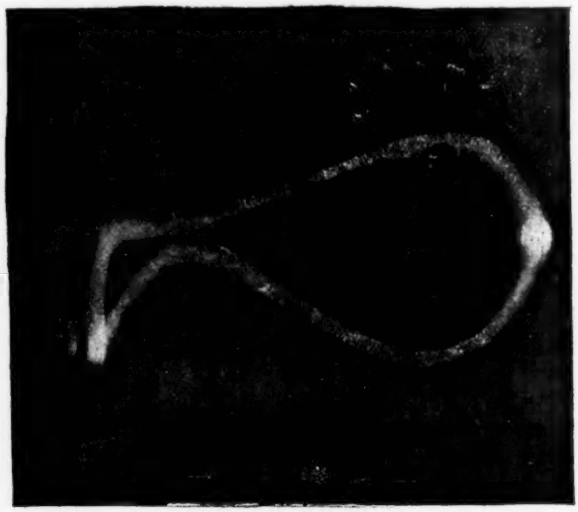

FIG. 203.

the metal the temperature of which it was desired to ascertain. The change in the electrical resistance due to change in temperature was shown by photographing the motion of a galvanometer mirror. The results in these cases confirm the work done by Adams, and the apparatus seems to be stable and reliable. The writer will try and present the results of these various investigations at a later meeting of the Society.

Mr. H. H. Suplee.—I think emphasis should be laid on the fact that an international system should be adopted, and that that should include not only England, but at least Germany and such other countries as would be willing to come in. I know that there is a very careful attempt now being made by the Society of

German Engineers to adopt a standard method of testing engines, and I think investigations have also been made in France, and it seems to me that if any committee is appointed for this purpose it should be international, just as the Committee on Standard Tests of Materials is international. I only offer that as a suggestion.

Mr. Francis H. Boyer.—Mr. Donkin's paper refers to the necessity of taking account of the effect of the temperature of cylinder walls in testing engines. We have had some very fine papers on cylinder condensation recently, and I would refer particularly to one by a junior member of the Society. By your permission I will use the board to make clear my point.

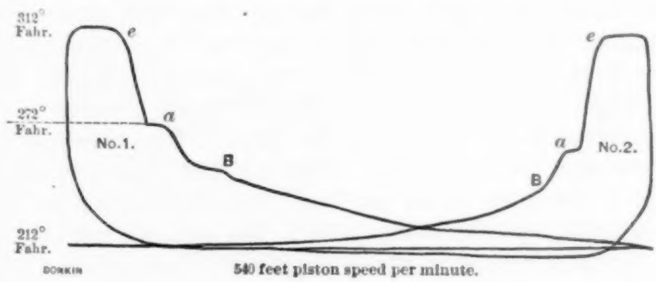

FIG 204.

In using the indicator, our instruments often show the effect of this cylinder wall condensation, and in this way. We will have an expansion curve starting off at cut-off and then a jog, and the curve is completed by another running down to the terminal point. I have often asked our makers why we do not produce as good variation cards with our American instruments as we can with the German ones. Their reply comes back that it is a defect in our instrument. I hold it is not. Let us consider the problem.

At atmospheric pressure of the exhaust line we have a temperature of 212 degrees. At 80 pounds steam we have a temperature of 312 pounds per square inch. Now, as this steam has entered the cylinder and the pressure falls after cut-off, the temperature reduces in the same proportion, and the water which has been condensed upon the cylinder walls becomes revaporized to the extent of the range of temperature between 312 and whatever temperature it may come. That causes this increase in pressure.

You can take, for instance, 272 degrees at the centre here, which would represent a falling off of 40 degrees, and at this point this condensation which is on the walls of the cylinder bursts forth, due to the amount of heat which is in excess, and which passes from the heat held in the water to a vapor. Dr. Emery, if he were here, I am sure, would bear me out in this, because I think it was some twenty years ago that he was called on by the Government to give a reason why it was not possible to heat water to an intense degree and let it burst into steam, the reason being, if I am correct, because there were not the heat units in the water sufficient to throw it into a hot vapor. Members who come from Boston may know about the attempt to put a heating system through Boston by hot water under pressure, and you know the terrible failure they had. Why was it? They had water up to a pressure of 500 pounds per square inch, but there was too little energy in the heated water itself; it is in the latent heat of steam that we get so much of energy, and that heating power the hot water did not have. There was the defect. That same law holds good in our indicator tests. Now we find this phenomenon mostly in our cylinders on our rapid engines, and engines which have a great cylinder sweep. As I just said, we get hold of a good many instruments which don't show that effect, and yet some of the German instruments will show it perfectly. I cannot explain it, but I would like to call the attention of the meeting to the fact.

*Mr. Bryan Donkin.**—I note with pleasure that the Council were authorized to appoint a committee to consider the question treated in these papers.†

With regard to Professor Carpenter's interesting remarks, I quite agree with him that it would be very desirable to retain the old standards of pounds of water per horse-power and boiler-power per horse-power, introducing at the same time the new and more accurate method of thermal units, as suggested.

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* Author's closure, under the Rules.

† The committee consisted of Messrs. Boyer, Barrus, Donkin, Jacobus, and Richmond.

DCCLXXXVII.*

SOME OF THE MECHANICAL FEATURES OF THE POWER DEVELOPMENT AT NIAGARA FALLS.

BY DR. COLEMAN SELLERS, PHILADELPHIA, PA.
(Member of the Society and Past President.)

In addressing you as chief engineer of the Niagara Falls Power Company, in regard to some of the mechanical features of the power development at Niagara Falls, I desire to make a brief statement concerning the organization of the company which has accomplished the work in question. It must be understood that the development thus far has been conducted by the Cataract Construction Company, the officers and directors of which practically control the allied corporations including the Niagara Falls Power Company, and have appointed the engineering staff by which the operations of these several companies have been conducted.

With confidence in the ultimate financial success of the project, the leading capitalists interested have patiently watched the progress of the work, and some from the outset have individually taken a prominent and active part in the consideration of the technical questions involved, as viewed from the standpoint of sound business experience. At times, under the advice of its engineering staff, the Cataract Construction Company has proceeded in direct opposition to the opinions of men prominent in the scientific world, after careful study of the questions presented from a commercial as well as from an engineering standpoint, realizing, as the results have since justified, that it was necessary so to act from full conviction in a matter where there was so little established precedent to serve as a guide.

The plan of utilizing the power of Niagara Falls as proposed by the late Thomas Evershed, while Chief Engineer of the State of New York, contemplated the construction of a tunnel under the town, which tunnel was to constitute a tail-race from the

* Presented at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

turbines or water wheels of factories to be located on land above the American Rapids, in contradistinction to the plan of placing the turbines and factories at the river below the Falls, and bringing the water to them by a long canal. The Evershed plan, while presenting great advantages, not only called for a large amount of capital, but the active influence of men of broad business experience, who possessed the confidence of leading financiers in this country and abroad. Mr. William B. Rankine and Mr. Francis Lynde Stetson were induced to take the matter up, and in 1889 sought the advice and coöperation of Mr. Edward D. Adams, of New York, who subsequently was elected president of the Cataract Construction Company.

These gentlemen, while appreciating the advantages offered by the Evershed plan, looked beyond the mere project of establishing factories operated independently by their respective water wheels, to the possibility of generating power at a central point where it could be utilized in the immediate neighborhood, or transmitted to a distance, after the manner practised abroad, particularly in Switzerland, where several such plants were in operation.

In 1890 Mr. Adams devised a plan whereby the Cataract Construction Company could become fully informed as to the then most approved methods of developing water power, and its transmission and utilization. Early in that year I was retained by the company as consulting engineer, and at Mr. Adams's request I joined him in London, where, through my membership in the Institution of Civil Engineers and our intimacy with scientists in England and on the Continent, Mr. Adams's plan of organizing the International Niagara Falls Commission was perfected. The object of this commission was to obtain and consider plans submitted by engineers and engineering firms, for the generation of power, and the transmission of that power to Buffalo and to other accessible markets. The engineers thus invited to submit plans received compensation on account of the expense involved, and had also an opportunity to obtain certain premiums if their plans proved deserving of such recognition.

You are all probably aware, from what has already been made known on the subject, that the amount of valuable information thus obtained seems now quite limited as compared to what has since been discovered and adopted. There were,

however, certain recommendations made, the most important of which determined the sizes of the units of power and the speed of the turbines. Five thousand horse-power for each unit of power was proposed as conservative and safe, although previously there had never been any turbines made of greater capacity than one thousand horse-power. Two hundred and fifty revolutions per minute was decided upon as the speed most likely to be advantageous in generating electricity, and this was adopted in advance of any decision as to the electrical system to be used. The turbines, of which I will speak later, were ordered on this basis, and their construction well advanced long before the dynamos had been ordered which they were to drive, and prior to the adoption of the alternating current as the electric system to be employed.

I am at liberty to say that although at the time of the meeting of the International Commission the consensus of opinion among electricians of note was decidedly in favor of the use of the direct current for the transmission of power, yet Mr. Adams, almost immediately upon his return from Europe, parted with his interest in electrical companies, that he might feel, without bias, free to adopt whatever system might be found, upon a careful investigation, to be the best for the ultimate success of the Niagara enterprise. Many of those who had invested largely in this enterprise were pecuniarily interested in furthering the construction of machinery for the direct current, yet Mr. Adams accepted the position of president of the Cataract Construction Company with the clear understanding with those interested with him in the undertaking, that he would be upheld by them if, in his judgment, the alternating current should prove to be the best system for this particular case. Many able engineers, at home and abroad, submitted to the commission ingenious and well-worked-out plans for the generation of power and its transmission, yet the Westinghouse Electric and Manufacturing Company, the makers of the dynamos now in use, refused to take part in the competition, feeling confident that any scheme presented in 1890 would not be such as they would be in position to offer three years later, by which time the Cataract Construction Company would have decided on the kind of current and the character of the machinery they would need to meet such demands as might be made to them for power.

Before proceeding to describe some of the most interesting of the mechanical features of the machinery to which I shall mainly direct your attention, I must explain the advantage gained by the adoption of the tunnel tail-race.

In regard to the tunnel proposed, the question has been repeatedly asked, even quite recently, what particular advantage the Evershed scheme of a tunnel tail-race has over a surface canal leading to the deep gorge below the Falls, at which point a much greater head for the turbines can be obtained than is now utilized on the land above the Falls. More than forty-five years ago a canal was built, which supplies water to factories which are situated on the high land bordering on the river below the Falls, by the shortest possible route obtainable through the city. This was on a right of way 100 feet wide (50 feet of which was made available in the first place). At the time that this canal was built the city was a mere village, and property had less value than at present. To develop the amount of power which is rendered available by the present tunnel, which avoids the surface of the ground and was obtainable without excessive cost for right of way, would require a surface canal of much more imposing dimensions than would at first appear to be necessary. Such a canal would have to be at least 300 feet wide, and from 15 to 20 feet deep, and would pass through valuable improved and unimproved city lots; and, furthermore, upon reaching the gorge there would be no large area available for the erection of many buildings.

The tunnel plan rendered available a large amount of relatively cheap unimproved land, which will give ample room for a great development of independent power plants; although, as a matter of fact, at the present time there is but one such, that of the Paper Company, which takes nominally about 7,200 horse-power in water from our canal and discharges into our tunnel.

The tunnel of the Niagara Falls Power Company, in a direct line from the power house to the lower river, can be relied upon to carry away the water from the turbines at a speed of at least 27 feet per second, and is sufficient in size to permit the utilization of 100,000 horse-power from wheels under 136 to 140 feet head. The details of the construction of the tunnel and of the canal which carries water to the wheels in the power house, as well as to the turbines in the great paper mill below the power house, have been already described by others.

As for the engineers engaged on the work, my own connection with the project began late in 1889, when I was asked to report on the practicability of transmitting power by electricity; and after visiting the location with Messrs. Adams, Stetson, and Rankine I submitted a report on the cost of tunnel and canal. I was then appointed consulting engineer and chairman of a board of engineers consisting of Albert H. Porter as resident engineer, Clemens Herschel as hydraulic engineer, George B. Burbank, engaged in the same work as Mr. Porter, and John Bogart, then Chief Engineer of the State of New York, as consulting engineer. Col. Theodore Turrettini, Director of the Public Works of Geneva, Switzerland, was also a member of this board and the foreign consulting representative, having supervision of the work and designs that were made in Switzerland by Messrs. Faesch & Piccard. W. A. Brackenridge, now resident engineer, was a division engineer for the Cataract Construction Company from April, 1891, to 1894; engineer in charge of work for Cataract Construction Company and associated companies from 1894 to 1898; and at the present time is engineer in charge of all construction work of the Cataract and associated companies, including the Niagara Falls Power Company, Niagara Development Company, Niagara Junction Railway Company, and the Niagara Falls Waterworks Company, and under his supervision and to his plans the extension of the wheel-pit has been made.

Mr. L. B. Stillwell, electrical director of the Cataract Construction Company and the Niagara Falls Power Company, has been for many years connected with the Westinghouse Electric and Manufacturing Company at Pittsburg, and as a member of the staff of that company has had charge of our work from 1893 in the interest of the Westinghouse Company. In 1890-91 he was in Europe studying the problem of electrical transmission of power, and is therefore an electrician possessed of the fullest knowledge of our present wants and of each step in the whole progress of the work. Since he has had supervision of the power as electrical director he has devoted much attention to novel devices required by the establishments taking power from the company, and to the introduction of safeguards against accidents of all kinds, not only to the electrical machinery in the power house, but to the lines of distribution. The amount of energy handled has for a long time been unpre-

cedented, and as each new unit is added and the load increased on all the dynamos working in parallel, the opportunity to obtain data of great importance has increased. Long series of experiments have been conducted with existing circuit-breakers and fuses, new lines of thought have been presented to the makers of electrical machinery, which have suggested appliances to enable them to meet the requirements of the largest power plant in the world, and to sustain and improve its record of stability.

It will be seen that the present engineering force has been educated up to the high requirements of an enterprise which is unique in more respects than mere size. As the plant has grown, as the output has increased, as new industries have called for new conditions, the work has been one long and exhaustive study on the part of the engineering force, with an earnest endeavor on the part of each to contribute his share to the perfection of the whole system.

While the tunnel was being excavated in 1890 I spent about nine months in Europe, until the termination of the duties of the Niagara Falls International Commission, returning to America early in 1891.

In November, 1892, the work undertaken by the Cataract Construction Company had reached a point of completion when it was deemed feasible to disband the board of engineers, and it was then decided that the organization so known should go out of existence, January 1, 1893. I was retained as consulting engineer during the important period of installation of the turbines, dynamos, the erection of the power house, and the solving of the mechanical problems connected therewith. Among matters requiring immediate attention, I may note the laying out of the power house for the architects, designing the sluice gates as part of the building, and determining the conditions requisite for an electric crane capable of handling 50 tons. In this case we required a length of hoisting rope sufficient for the deep wheel-pit without coiling the rope more than one layer on the drum, and with a sufficient travel between side and end walls of the building to handle all the machinery to be erected. I name this one item among the many problems to be considered, as showing a principle which has been adhered to as far as possible. The conditions required for the crane were stated to crane-builders, and the order finally awarded to Messrs. William Sellers & Co.,

Incorporated, of Philadelphia, who designed and built for us a 50-ton crane, operated by one single electric motor, which has given entire satisfaction, and is an admirable example of the good result obtained by enlisting the best efforts of those skilled in any particular line of machine construction. The crane which has been so admirably adapted to the installation of our work is furnished with a separate rapid hoisting device for light loads, of sufficient length of hoist to reach the bottom of the wheel-pit, many feet below what is absolutely required for the installation of the heavy machinery. The two separate hoisting systems are operated by the same motor and handled by the same levers, with the advantage that the light loads are lifted at very considerable velocity of hoist, as the whole power of the large motor is at such time utilized to advantage for this purpose.

It has been the constant policy of the company to have its engineers, so far as possible, express the requirements of any machinery needed, and to ask builders of such machinery for designs which should fully meet the specification of requirements, such machinery to be fully guaranteed by the makers, and subject to the approval of the chief engineer. This has diminished the risk and secured the best results from engineering establishments working under the supervision of the chief engineer, and embodying his ideas in the work required. There were, however, many things so different from ordinary practice that special designs had to be made, but we have always been ready to modify the details to adapt the work to the shop practice and facilities of the maker who undertook to fill the order, in each case it being required that the builder should approve the design in accepting the order and to guarantee performance, workmanship, and material. In the case of the new turbines for the extension of the power, however, and already tested, the American makers guaranteed material and workmanship only, the principle having proved satisfactory.

The necessity of combining a fly-wheel or its equivalent with turbines driving dynamos which require close regulation as to speed had, previous to what we have done, attracted little attention in America, either from builders or users of water wheels or the makers of water-wheel governors. The weight of fly-wheels in connection with turbines of 5,000 horse-power making 250 revolutions per minute had been considered by the members of the commission at the meeting in London, January, 1891,

while discussing the various plans submitted to them. No wheel-builder in Europe had deemed it possible to find a dynamo design with sufficient fly-wheel effect from the speed and weight of the revolving parts of the dynamo alone. (In consulting my notes of the conference I find reference to a French engineer who says that in his judgment a turbine of 12,000 horse-power directly connected by a vertical shaft to a dynamo involves no experimental features, as it may be compared to an engine of 12,000 horse-power in a steamship driving the propeller by means of a long line of shafting, and there would be less frictional resistance in the few journals of the turbines and dynamos than in the case of the propeller shaft.) Messrs. Faesch & Piccard, of Geneva, Switzerland, in presenting their first design to the Commission, insisted on the need of a fly-wheel, and gave their formula of weight and speed per horse-power over and above what might be had from dynamos of equivalent power, assuming that the revolving parts of such dynamos would not be sufficient, their statement being: "If it takes 20 seconds to close the aperture for the water, the fly-wheel must contain energy equal to 4 seconds' work of the turbines"—this relating to their own design of regulator.

Fig. 208 shows a section of the turbine chamber and penstock with the first section of the hollow driving shaft and a fly-wheel, 14 feet in diameter, weighing about 20,000 pounds, which they prescribed in the design accepted by the Cataract Construction Co. These fly-wheels were embodied in the order for the turbines before any decision had been reached as to the kind of dynamo or the nature of the current to be used.

In discussing the problem of the fly-wheel as proposed by Messrs. Faesch & Piccard with their engineer, Mr. Baumann, I found that he agreed with me as to the desirability of doing away with a fly-wheel separate and distinct from the revolving parts of the dynamo, yet acting in conjunction with these parts. I suggested the possibility of insisting upon dynamos, whether with revolving armatures or not, being so built as to combine with the revolving parts of the dynamo a weighted mass or ring which would give the fly-wheel effect required, one idea being to make the armature core form part of the fly-wheel itself, the rim of the fly-wheel extending under and revolving beneath the stationary field. This was before the use of the revolving field ring in the manner suggested by Professor Forbes, and Messrs.

Faesch & Piccard were very ready to accede to the proposal, and I was authorized to countermand the separate fly-wheels. In asking for bids for dynamos later I imposed uniform conditions

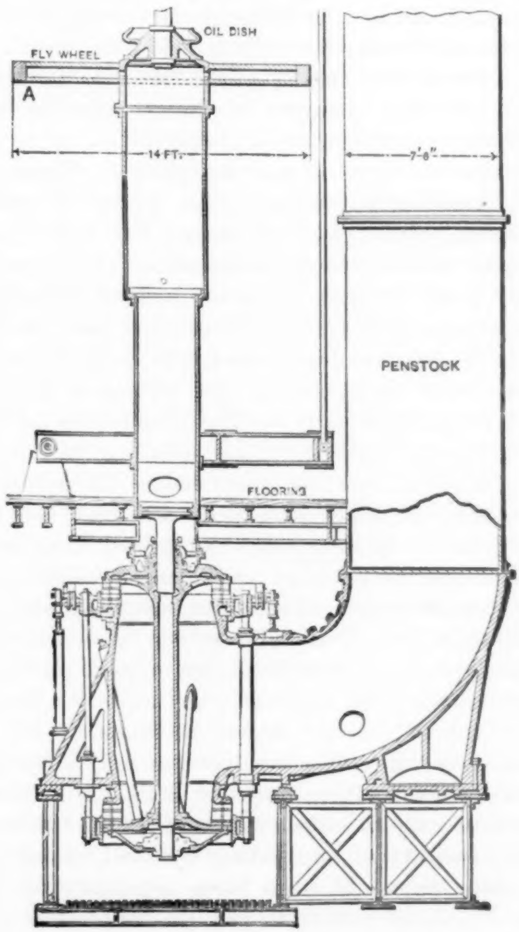


FIG. 208.

as part of the design which would be acceptable, namely, that the revolving parts of the dynamo should be so made that their weight computed as acting at a radius of gyration should be such that the product of this weight in pounds into the square of the velocity in feet per second should be not less than

1,100,000,000. Doing away with the fly-wheel necessitated an alteration in the lower section of the hollow shaft of the turbine, a steel casting being required to take the place of the hub of the fly-wheel as originally proposed. This important change, carried out in a far more perfect manner by the adoption of Professor Forbes's revolving field outside of a stationary armature, has enabled the fly-wheel effect to be increased to a greater amount than required by the specification, with a very decided advantage in regulation of speed.

The turbines we have in use, designed by Messrs. Faesch & Piccard, of Geneva, Switzerland, have proved so efficient that in the extension of the plant no change has been made in any essential part of the wheels themselves. The changes which I shall mention later, namely, as to the method of supporting the wheel chamber and the penstock, etc., are matters which have been carefully considered and approved by the original designers. Whatever I have to say to you in regard to the changes which had to be made with the first wheels, the use of Babbitt metal and the redesigning of the bearings must not be considered as derogatory to the engineering ability displayed by the Swiss firm, as what they proposed had the warrant of common practice. In many respects, indeed, they ventured out of the usual line of practice, and their foresight has proved correct in some instances where their design and deviation from precedent might have been adversely criticised in the light of our then limited experience with large units of power.

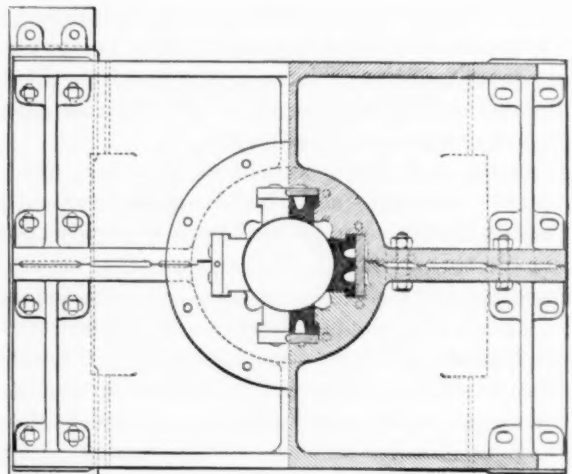
This, for instance, was eminently the case with the size of the penstock, which is 7 feet 6 inches in diameter for wheels of 5,000 horse-power, involving a velocity of fully 9 feet per second at full load, when common practice calls for 2½ to 3 feet per second, as necessary to obtain the best results; but in this instance the necessity of supporting by steel beams so large a mass of water as would have been necessary to obtain the lower velocity, decided them to risk the theoretical sacrifice of one foot in head to increase the velocity from 2 feet to 9 feet, and so to form the penstock connections as to avoid interrupting the flow of the water by sharp bends.

The length of the penstock is in fact short as compared to its diameter; its wet perimeter is short in proportion to the area of the pipe. At its upper end, where the water enters, the area is double that of the vertical section. Without being able to

give the exact efficiency of the turbines, we are satisfied with the results. Turbines estimated to yield 5,300 horse-power at full gate, at 75 per cent. efficiency, having delivered from the dynamos 5,400 estimated horse-power, we know that the real efficiency of the wheels is in excess of 75 per cent.

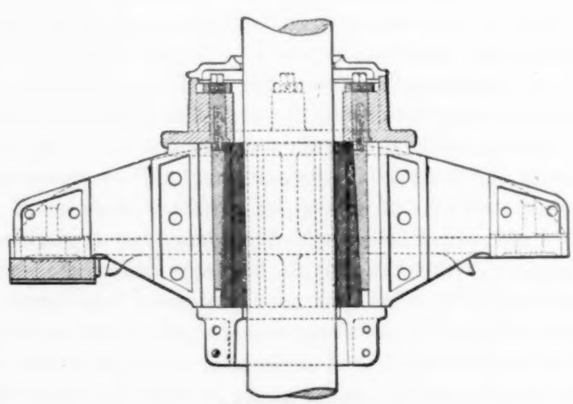
Babbitt metal and other anti-friction metals are used in America not for economy's sake, but for good practical reasons, but such metals do not seem to have been as highly appreciated in Europe as in this country. The specification issued by the Swiss engineering firm for the turbines and machinery called for bearings made of phosphor bronze. The Phosphor Bronze Company in Philadelphia were consulted as to the different grades of metal they made, and recommended a peculiar grade suitable for this case, presumably containing more or less lead. My experience, however, has led me to place more reliance on the best grades of anti-friction metal, on a base or support of a proper quality of bronze, in case the anti-friction metal should give way and the shaft come in contact with the bronze.

Figures 209 and 210 show a four-parted bearing with wedges back of the bearing blocks to set the bronze bearings up to the shaft adjusted by screws, as originally designed in Switzerland, and in accordance with the common practice of many able engineers. The adjustment in this manner of four separate brasses serves no good purpose in alignment. The wedges can only control the contact with the shaft, and cannot be made to affect alignment, if the axis of the bearing as fixed in place does not coincide with the axis of the shaft which is supported by the bearing. Professor Forbes, who for a time was consulting electrical engineer for the company, in his early design of the dynamo with rotating field ring as now used, proposed four-parted bearings similar to those on the water-wheel shaft for the vertical shaft of the dynamo, for the sake of uniformity throughout the system. I objected to this design, as far as its mechanical features were concerned; a new design was made under my direction, to embody Professor Forbes' electrical system. We were fortunate in being able to secure as draughtsman the services of Mr. Baumann, the engineer of Faesch & Piccard, who was in this country superintending the construction and erection of the hydraulic machinery of practically his design. He is an excellent draughtsman, a capable engineer, quick to appreciate the arguments advanced as to the desirability of having a continuous metallic



Plan
INTERMEDIATE BEARING
AS DESIGNED BY FAESCH & PICCARD
COLEMAN SELLERS

FIG. 209.



Vertical Section
INTERMEDIATE BEARING
AS DESIGNED BY FAESCH & PICCARD
COLEMAN SELLERS

FIG. 210.

surface in the case of the dynamo bearings, which bearings must be of such a character as to be able to support the revolving shaft no matter in what direction the pressure may fall upon the bearings. Anticipating trouble with the water-wheel shaft

bearings, I designed a set of bearings and had them made similar to those of my design already in successful operation on the dynamo.

The experience obtained in starting this new machinery is worthy of your careful attention. That you may understand the case more readily, I may say that the vertical shaft connecting the turbines to the dynamo is formed of steel tubes 38 inches external diameter, made in all respects similar to the tubes of furnaces of marine engines (see Fig. 211). As these tubes could not be obtained of sufficient length, a number of them were coupled together by flanges made of rolled steel angles to make the length required, there being two intermediate bearings only between the upper solid shaft coupled to the dynamo and the solid shaft in the wheel case. Spindles of steel 11 inches in diameter were introduced at the bearings where such support was required. By this means the shaft was made light, and the bearings reduced to a minimum in number. In the wheel case proper there are two oiled bearings on a solid shaft. Immediately below the dynamo there is a thrust bearing fitted to ten rings on this section of shaft, and between the thrust bearing and the wheel case are the two intermediate bearings which steady the vertical shaft, and it is to these two bearings that I first call your attention.

The lubrication of the four-part bearing as shown by Fig. 210 was to have been effected by means of oil contained in an annular dish bolted to the upper end of the coupling of the hollow shaft below each bearing. Into this dish, which revolves with the shaft, a pipe was made to dip with a scoop end so arranged that in the rapid revolution of the shaft the oil carried around by the dish would come in contact with the scoop end, and be thus forced vertically to the upper end of the bearing and pour down through the bearing, the operation being similar to the present method of taking the water supply from stationary troughs between the rails by express trains, only in this case the scoop would remain stationary and the oil would be presented to it at a velocity of about 22 miles per hour. This arrangement was abandoned, and stuffing boxes were placed below each bearing, in order that the bearing might be filled with oil, and the shaft revolve in a bath of the lubricant. It was soon demonstrated that the shaft 11 inches in diameter, running at the rate of 250 revolutions per minute, with oil of the proper degree of viscosity,

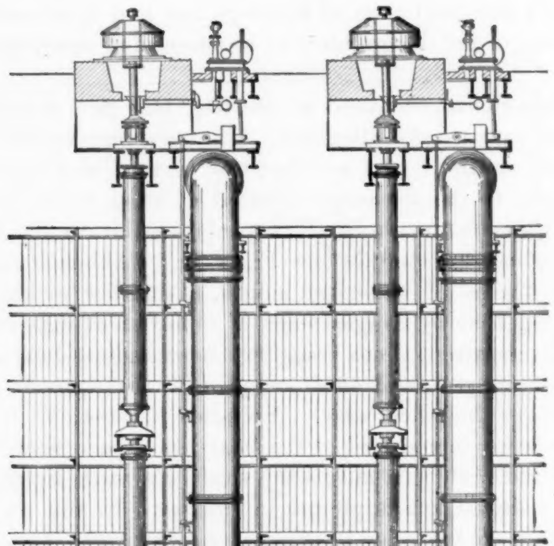


FIG. 211.—GENERAL ELEVATION. FAESCH & PICCARD DESIGN.

was rapidly heated owing to the motion of the shaft only, precisely as in the case of Joule's experiments in determining the mechanical equivalent of heat. After weeks of trial and no end of careful work to scrape the bearings to a good fit on the shaft,

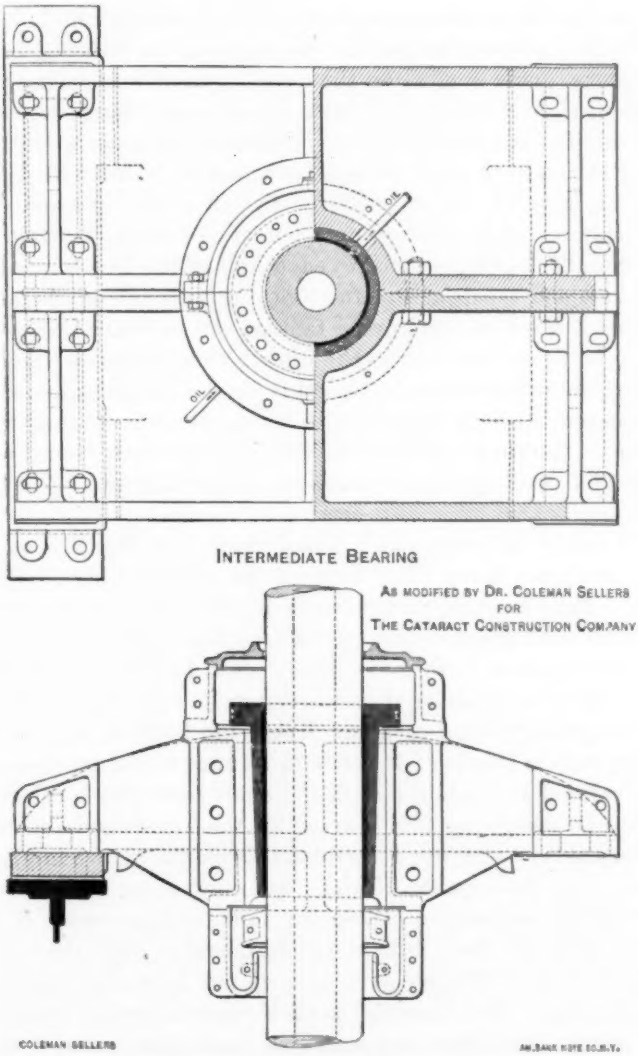


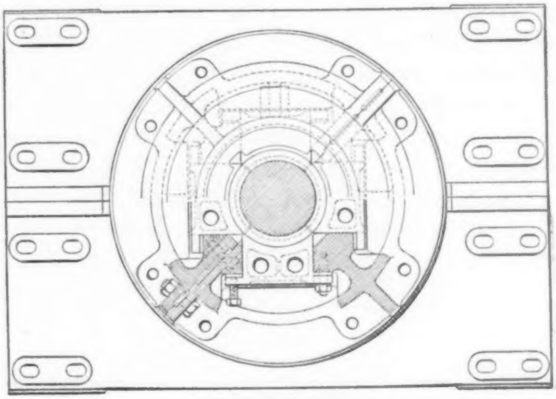
FIG. 212.

it was found impossible to keep the machinery up to speed without cutting, while the bearings in the dynamo, to which I have already alluded, having shafts nearly two inches larger in diameter than the turbine shaft, ran perfectly cool and in a satisfactory manner. It was decided then to take out the four-parted

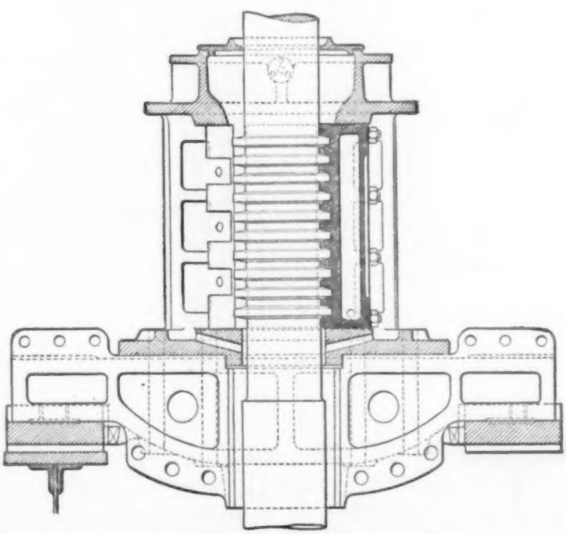
box and put in a bearing similar to that shown on Fig. 212, which you will observe is simple in construction, the bearing being in two parts, made conical on the outside, the joints being practically oil tight when forced down by an upper flange to secure a firm anti-friction lining. These half-boxes are lined with Babbitt metal throughout their entire length, and provided with diagonal grooves for the distribution of the oil; the grooves extend to within $\frac{1}{2}$ inch of the top and bottom of each bearing. The oil brought under pressure to each half of the bearing encircles the shaft and escapes top and bottom into oil catchers, from whence it flows to a receiving tank at the bottom of the wheel-pit, to be again elevated to the distributing tanks at the upper part of the power house. No oil is used a second time until it has passed through the proper filtering devices to render it fit for use. Bearings arranged in this manner have been running since 1895, and apparently show no wear whatever. They keep quite cool.

The thrust bearings which I now show you, Fig. 213, as originally designed have their four-parted bronze liners bolted to place. Each bearing so formed is bored out to fit the rings on the shaft with great accuracy. These bearings had to be faced with anti-friction metal before they could be prevented from cutting. They have since then worked well. In case of accident, one complete bearing case and liners are kept on hand so as to relieve such a bearing; it needs to be sent to the machine shop to be relined and rebored to fit the shaft from which it has been taken. In designing this bearing for the fourth and succeeding turbines as now running, I modified this part as shown in Fig. 214, diminishing the number of rings but increasing their strength and bearing surface, applying the anti-friction metal in such manner that the shaft is held in alignment by the shaft proper at the bottom of the steel rings, and not by the circumference of those rings. This bearing has each separate bronze block faced with white metal-lined segments, so made that when detached from the blocks to which they are secured they can be relined with Babbitt and dressed to a template in any ordinary lathe. This makes the parts interchangeable, and greatly diminishes the cost of repairs.

I will now call your attention to a very interesting experience with the oiled bearings in the wheel-case. An attractive feature of the Faesch & Piccard design of the turbines is that their



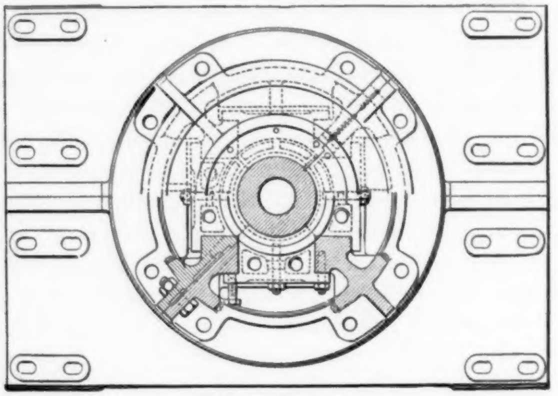
THRUST BEARING
AS DESIGNED BY FAESCH & PICCARD



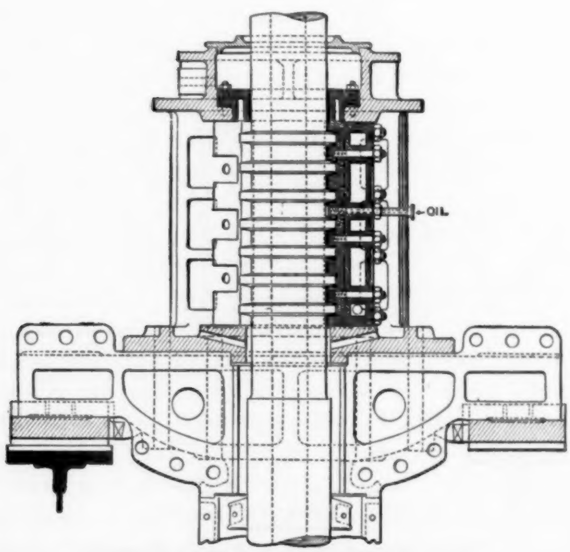
THRUST BEARING OF NO. 1, 2 AND 3 TURBINES.
COLEMAN SELLERS

FIG. 213.

wheel-case bearings are excluded from all chance of water mixing with the oil. I have been asked by turbine makers why water lubrication has not been relied on for such bearings. The water of the Niagara River is not always free from mud; at times it is very turbid. The great size of the units adopted, the



THRUST BEARING
AS MODIFIED BY DR. COLEMAN SELLERS
FOR
THE CATARACT CONSTRUCTION COMPANY.



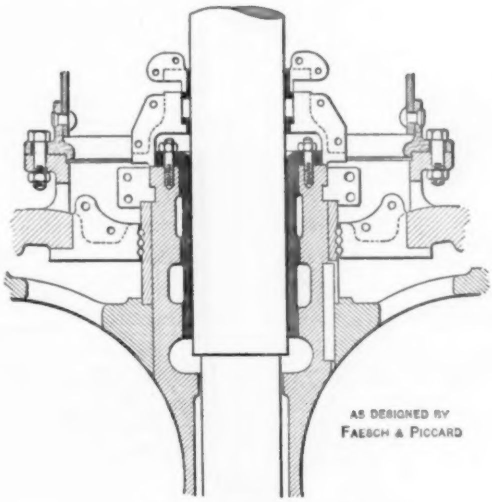
THRUST BEARINGS OF NEW TURBINES.

COLEMAN SELLERS

FIG. 214.

diameter of the shafts and their high surface speed, call for good lubrication, and exclusion of all abrading matter. Fig. 215 shows the bearings as designed for the upper bearing in the wheel-case. You will observe that the bronze bushing in this

case is made in halves and not four-parted; the outside of the bronze is in steps, each one from the top down being less in diameter than the one above it—this to facilitate removal. There are air spaces shown between each two steps. Bearings thus made not only cut badly, but showed an expansion of the metal into the air spaces. The flood of water outside these bearings did not prevent the heat-rise mentioned. The air spaces were then filled up with type metal, and the bronze bushing lined with Babbitt metal. Since then there has been no wear and they have run cool.



UPPER TURBINE BEARING

FIG. 215.

In redesigning the wheel-case, as I will presently show you, I made the bushings conical on the outside (see Fig. 216), to give metal contact to conduct away all the heat from friction. The wheel-case bearings being oiled by drop oilers, there was no provision to catch the oil and return it for re-use. (See Fig. 217.) I have since arranged an oil dish to catch the oil thrown from the lower bearing by the protruding shaft, the oil being thrown into a well, from which it can be raised by a small pump, one of the three large bolts which support the bottom of the wheel-case being bored throughout its length and fitted with a check valve at its lower end, where it dips into the oil well. A small pump driven

by water near each turbine lifts the oil to the common reservoir for all the bearings. This permits one quality of oil to be used throughout the whole system. My design of bearing for these vertical shafts permits the free use of a pure mineral oil, distributed freely for lubricating and cooling, thus reducing the friction to a minimum. The Faesch & Piccard design of turbine and vertical shaft had a great advantage in regard to low frictional resistance, the changes made by me in detail being in the direction of simplicity in the parts, and were the utilization of my half a century's experience in constructing shafting and

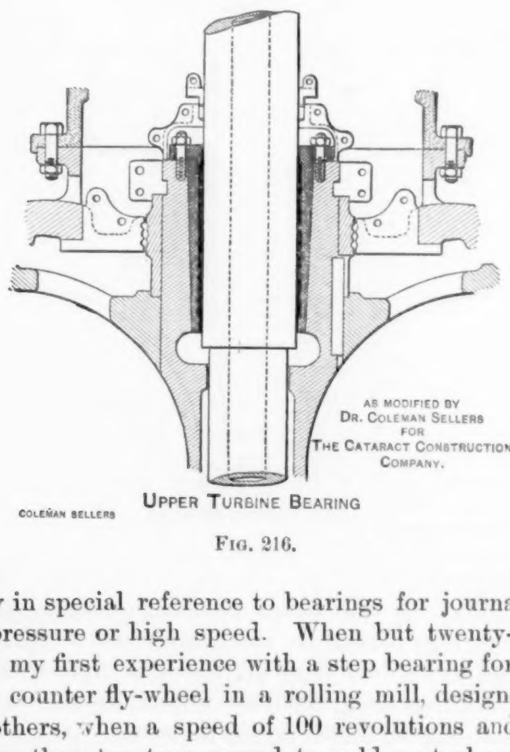
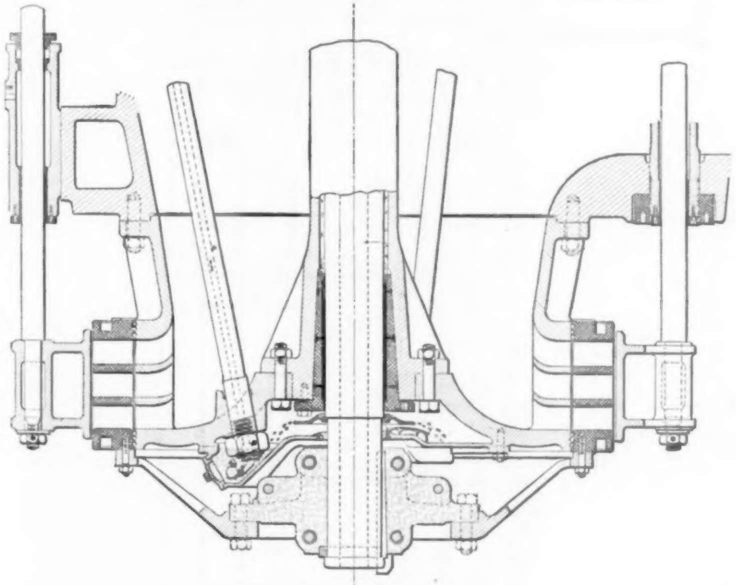


FIG. 216.

machinery in special reference to bearings for journals subject to great pressure or high speed. When but twenty-two years old I had my first experience with a step bearing for a vertical shaft of a counter fly-wheel in a rolling mill, designed by one of my brothers, when a speed of 100 revolutions and a weight of not more than ten tons served to weld a steel spindle step to a steel seat plate five inches diameter, when step and seat were flooded with cold water. Now we are dealing successfully with a weight of 160,000 pounds, or eighty tons, at a rotating speed of 250 revolutions per minute.

The friction of all the parts of the vertical shaft, including the

bearing in the dynamo and all the revolving parts, is so slight that when the ring gates which regulate the speed of the turbines are entirely closed, and no water can escape from the wheels except what leaks through the slight opening between the gates and the wheel, the rotation of the machinery continues at about forty revolutions per minute after the load is thrown off; and therefore, in stopping we are obliged to continue the load until the speed is reduced sufficiently to apply a pneumatic brake,



SECTION OF LOWER TURBINE, ETC.

SHOWING IMPROVED FORM OF BEARING AND OIL RECOVERING DEVICE,

DESIGNED BY DR. COLEMAN SELLERS, FOR THE CATARACT CONSTRUCTION COMPANY

FIG. 217.

which finally arrests the motion and prevents revolution until the main sluice gates can be closed and the water run out of the penstock.

The three turbines which have been in constant operation since 1895 are supported by heavy steel beams crossing the wheel-pit where the brick side walls narrow the pit to a width of sixteen feet. These beams, six feet deep, were designed to span a width of twenty feet in the clear; they have fixed end supports, as they not only rest on and are built into walls over two feet

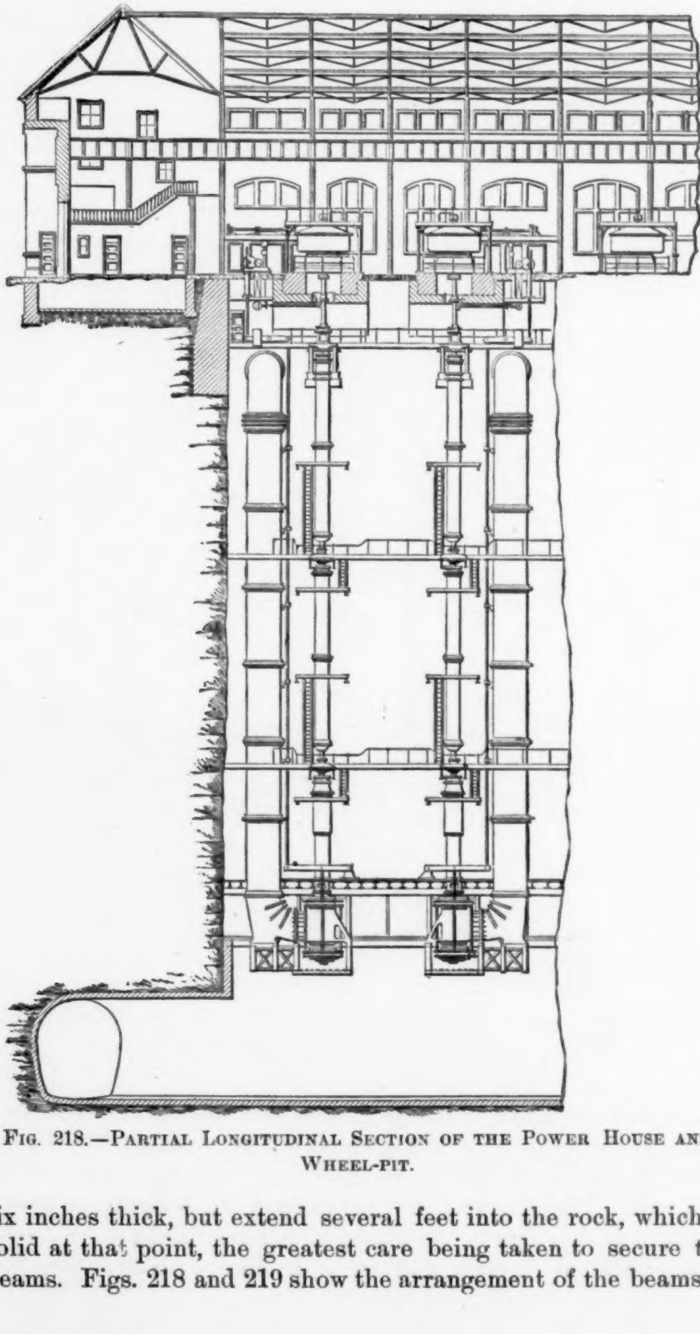


FIG. 218.—PARTIAL LONGITUDINAL SECTION OF THE POWER HOUSE AND WHEEL-PIT.

six inches thick, but extend several feet into the rock, which is solid at that point, the greatest care being taken to secure the beams. Figs. 218 and 219 show the arrangement of the beams to

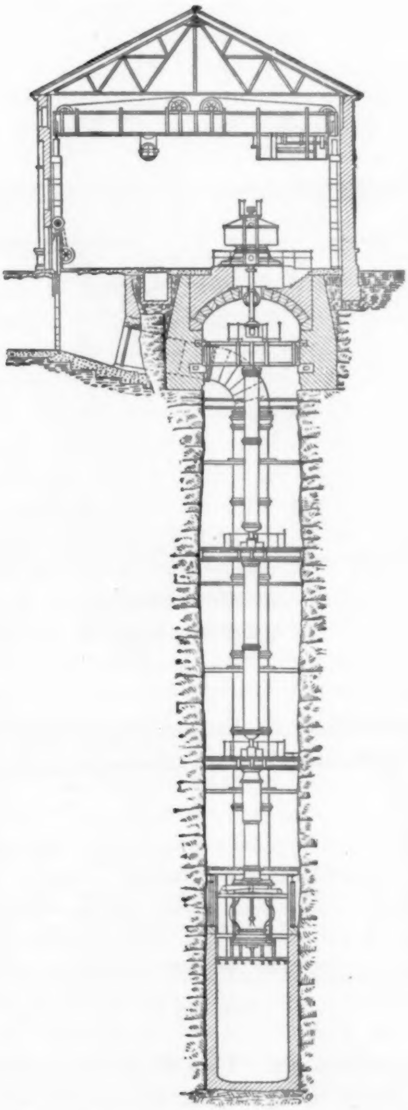


FIG. 219.—CROSS SECTION OF POWER HOUSE AND WHEEL-PIT.

support the wheel-case and the penstock of wheels 1, 2, and 3. Fig. 220 shows the change I have made in the mode of supporting the wheel-case of all the wheels that are being erected

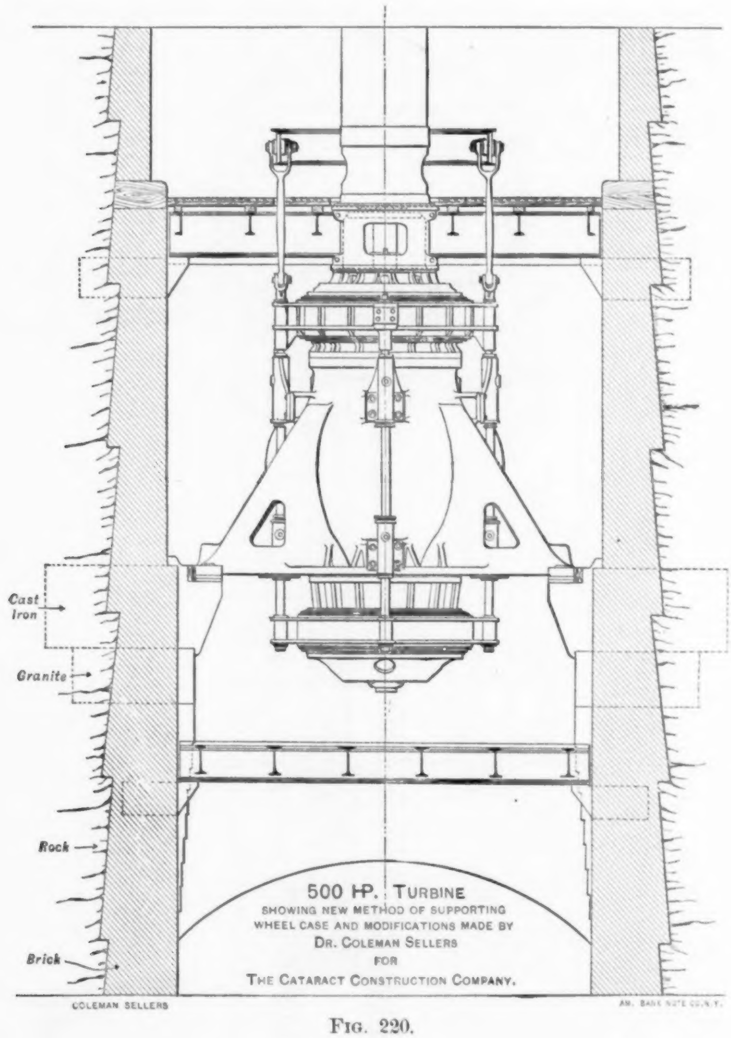


FIG. 220.

in the extension of the pit. This illustration shows the brick lining, and the stone sides of the pit as cut out by means of channeling machines.

In executing this part of the work, Mr. Brackenridge has exercised the utmost care to establish drains between the brick walls and the rock by vertical wooden troughs or boxes with lateral horizontal hollow brick drains at stated intervals in the

wall, to insure a free passage for the rock water to escape into the tail race, and to keep the pit dry after these walls shall have been carried to the top. You will observe that I have done away with the steel beams shown in Figs. 218 and 219, and support the wheel-case, as also the penstock, by brackets projecting from each side of the main casting to such width as to receive abundant support on heavy iron castings built into the walls and into the rock back of the walls. These castings rest on huge granite blocks, supported in turn by the brick walls racked out to carry them. Steel wedges are driven in between the ends of the base of the brackets and the castings, set in the walls so as to put the lower member of the brackets under slight compression and to insure an even distribution of the weight over the whole surface of the granite blocks. An iron grated floor is placed below each lower turbine, so that workmen can get at the wheel without being restricted by any beams, such as are used to support the first three wheels and penstocks.

Turbines Nos. 1, 2, and 3 are regulated in speed by the well-known relay governor of Messrs. Faesch & Piccard, having the gearing which moves the ring gates operated by clutches put in motion by changes of speed, the rise or fall of the governor balls letting one or another pawl act on a ratchet wheel to give motion through the clutches and gearing to a heavy rack connected by a rod to a lever on the beams which support the thrust-bearing deck. This lever carries a weight of several thousand pounds adjustable on one end so as to balance the weight of the ring gates, which when shut prevent the escape of water from the turbines except what leaks past the ring gate top and bottom, the space between the inside of these rings and the outside of turbine runners being not quite $\frac{1}{16}$ of an inch. The ring gates of Nos. 1, 2, and 3 turbines open by moving downwards and close by the opposite motion, the consequence being that as each turbine is divided by partitions into three sections, the lower section of both wheels is not opened for escape of water except at full load. Any small stones passing down with the water and being washed through the distributor are not able to escape from the buckets, and are liable to collect and grind against the ring, or might accumulate and chip the blades of the distributor or wheel. Due precautions have been taken to prevent the stones getting into the wheels, and no trouble has resulted from this cause. The advantage of opening the gate

downwards lies in the fact that it is safer to allow the gates to fall open suddenly in case of accident to the connecting rods than to fall shut, as in the latter event a too sudden interruption of the velocity of the escaping water would create a force upwards far greater than 160,000 pounds, and might destroy the machinery. The new wheels have been altered to make the gate open upwards; 1st, to permit the escape of accumulated matter from the lowest section of the bottom wheel, and also to prevent the upward escape of the water with violence against the turbine deck, which occurs when the motion of opening is downward. To make the machinery safe from accident incident to breakage of the connecting rods and a too sudden closing of the gate, a dash-pot is provided to the lower lever which controls the gate motion, the dash-pot offering resistance only when the speed of closing is greater than twenty inches motion in six seconds of time. Understanding this, you will appreciate the seeming difference of the rack movement of No. 3 and No. 4 wheels, as the latter is closed when the rack is at the top of its stroke, while the racks of Nos. 1, 2, and 3 are closed when the rack is at the bottom of the stroke, 3 inches motion of each in either case causing 1 inch of gate movement. A careful study of the action of the governors in use since 1895 has led to the adoption of some changes in the governing machinery, which I cannot dwell upon at this time, but which will, it is expected, improve regulation and diminish risk of accident from sudden stoppage of the exciting current from any cause whatever. My aim has been to interest the best talent of our engineering force in suggesting changes which will diminish the risk due to the personal equation of the attendants and to place some essential actions of the governor under the control of the men on the operating platform, so that any action of the electrician in charge which would under ordinary conditions require the attendant on the power-house floor to act in conjunction with the electrician will be done away with and the electrician's action will anticipate the change of speed of the turbines incident to the causes not under the control of the attendants on the floor, but always incident to the action of the men on the platform, or to meet the effect of accidental short-circuiting at or near the power house.

After running three turbines since 1895, arrangements were made to increase the power plant. In extending the wheel-pit

for the reception of five additional turbines and dynamos to the three originally installed, a space has been reserved between Nos. 5 and 6 units for the installation of four turbines of 200 horse-power each, to drive four direct current dynamos. These are located symmetrically about an ornamental structure over the hoistway of an hydraulic passenger elevator. These dynamos are to furnish direct current of required voltage, one of each to feed the field magnets of five of the large dynamos ; others to furnish power to the travelling crane, the sluice-gate motors, to operate arc lights, and to do any work requiring direct current, without resorting to reconversion of the alternating current into direct current by rotary transformers. These direct current dynamos, as I have said, being used one for each group of five large units, will insure more steady regulation of the current delivered than is possible when they are made self-exciting through rotary transformers, as in that case the feeding current varies with the changes in the alternating current due to change in load, the effect being as the square of the difference. Until the wheel-pit had been extended these separate exciting wheels were not practicable for want of room in the wheel-pit. Their installation, however, is in accordance with our original intention. The turbines selected were furnished by the S. Morgan Smith Co., of York, Pa. ; the dynamos, of 125 kilowatts capacity, by the Westinghouse E. & M. Co., of Pittsburg, their design being in keeping with their other work in the power house.

In my enforced brief description of the dynamos which form the important part of the largest power plant in the world, I have been obliged to use for illustration of my subject pictures taken from the drawings used in constructing the three machines you saw in operation, which have been doing remarkably well since they were started in 1895. Five new dynamos at the time of this meeting have their several parts separate and in various stages of erection on the power-house floor. I can now use for illustration the pictures taken from the new machines. The changes which have been made in the design since the first machines were built would be perhaps unnoticed unless your attention was called to them. An important feature of the original design as made under my direction is in the character of the bearings supported in the spider frame (Fig. 221) which is centred by the cast-iron support for the armature core (Fig. 225).

This feature of the design permits the stationary armature, supported by the bed plate of the machine, to be left intact with all its electrical attachments, while the field ring with its magnets can be lifted off, and the spider frame (Fig. 221) taken out, so as to leave a clear space of not less than five feet in diameter. Through this space the hoisting ropes from the travelling crane can be passed to remove or adjust any parts of the turbine machinery directly below the dynamo. The various parts of each dynamo have been made accessible for repairs with ease and without dismantling the machine. Thus any field magnet and its bobbin or exciting coil (see Fig. 223) can be taken out without lifting the field ring from its place. The

FIG. 221. — SIDE VIEW OF CASTING CARRYING SPIDER FOR BEARINGS.

FIG. 222. — END VIEW OF THE CASTING.

bearing brasses, lined with Babbitt metal (see Fig. 225), can be each taken out or adjusted when required with the greatest ease. The cast steel driver (Fig. 226) which carries the field ring at its outer edge, has, in the new machines, openings provided for the escape of air, these air spaces being provided with an adjustable cover that enables them to be regulated as to size.

The first three dynamos developed more heat than desirable. To reduce the temperature I suggested water jackets inside of the armature core. This application of water was eminently successful. In the new machines a few changes were made in the ventilating spaces in the armature core, and passages for water circulation have been provided for in the cast iron frame

that carries the armature core (see Fig. 227). The Westinghouse E. & M. Co., in redesigning the dynamos with the knowledge obtained from the first machines, have so improved the de-

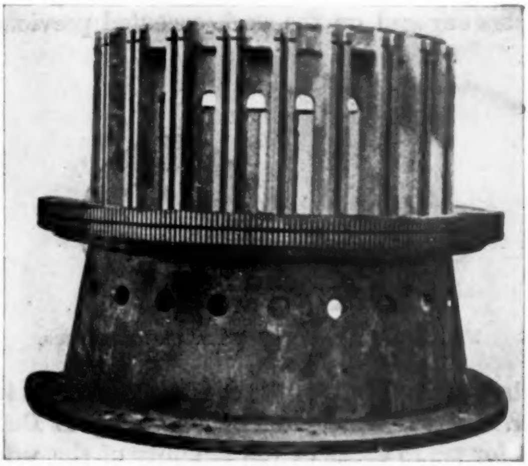


FIG. 223.

sign as to diminish the copper and iron losses so as to keep the temperature down to the requirements of the specification

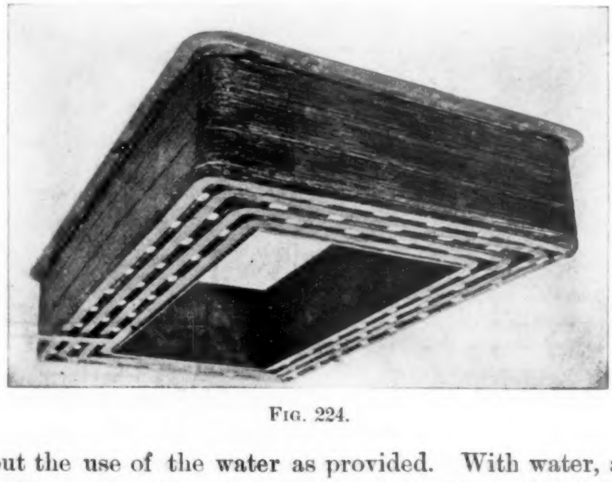


FIG. 224.

without the use of the water as provided. With water, at full load, the temperature rise can be kept down to 40 degrees Cent.

I cannot do better than refer you to Mr. L. B. Stillwell's very full description of the first dynamos of 5,000 horse-power, as published in *Cassier's Magazine* of July 5, 1895. In the same number of *Cassier's Magazine* will be found descriptive papers by the engineers engaged on the work executed previous to 1895,

FIG. 225.—DETAILS OF ARMATURE BEARINGS.

as, for instance, the details of the construction of the tunnel tail-race by Mr. Albert H. Porter and by Mr. George B. Burbank, and it remains for me to speak of the stability of the work as executed. The tunnel was to have been a rock excavation without

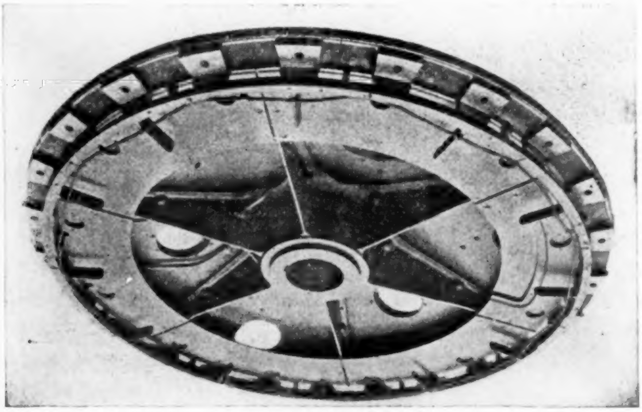


FIG. 226.

lining of any kind. A lining of some kind was, however, found to be essential. The Board of Engineers decided upon brick as most suitable, the brick to be of the best quality hard burned, the surface layers of the invert, and about seven courses of the side walls rising from the invert on each side, to be of a very good

quality of vitrified brick. About that time Mr. John Bogart presented to the Board of Engineers brick taken from sewers in New York City which had been in use about seven years. These bricks, set in the invert of the sewers, had worn away to the extent of fully 25 per cent. from their original size as set; on edge, the worn surface presented a convex surface, the wear being greatest at the joints on each side. Assuming the wear to be from sand carried by the water, the sewer having an incline of 7 feet per 1,000 feet, about the same as the hydraulic slope of the Niagara Falls tunnel, I felt the need of some test

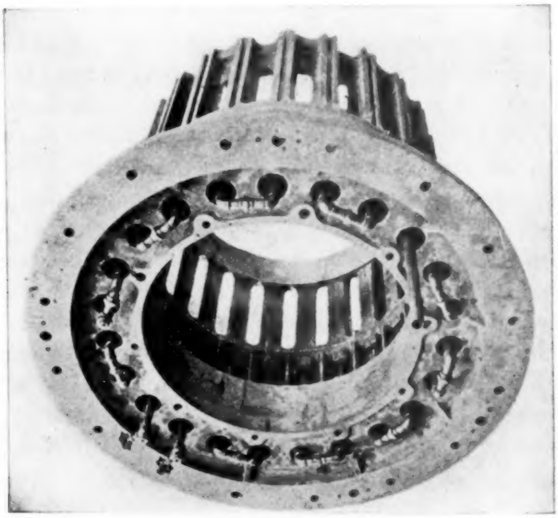


Fig. 227.

as to the durability of the brick to be used, and decided to try the sand blast for this purpose. Testing glass under a discharge of a fixed quantity of sand of uniform quality driven by an air blast of five pounds to the square inch with specimens placed $\frac{1}{2}$-inch from the discharge nozzle, I found that at each of, say, four trials a depression was cut in the glass; the quantity of glass removed at each trial was so uniform in bulk that my most delicate balance used for chemical analysis failed to detect an appreciable difference in weight in each specimen. Applying the same test to various materials used in our structural work, I established the fact that when the material was

uniform in composition, as in the case of samples made up of neat cement, hard-burned brick, marble, and some limestones, the same uniformity was observable. With briquettes of cement and sand the variation is increased by the possible loosening of more or less grains of sand from the bond of cement, but in the worst cases an average of four blasts applied to each specimen held well for many samples of the same material.

After numerous trials I was able to tabulate results which gave an excellent idea as to the utility of each substance used to stand abrasive action of sand carried by the water. When I came to apply the sand-blast test to the vitrified brick used in the invert, I was agreeably surprised to find that in no case did a sand blast which was sufficient to make a very marked deformation of the surface of ordinary glass, such as is used for mounting specimens for the microscope or on granite, or hard-burned red brick, or Queenstown limestone, etc., make the slightest impression on the smooth surface of the vitrified brick. In point of fact, the pellets of sand rebounded, acting precisely like a hardened steel ball $\frac{3}{8}$-inch diameter, dropped from a height of, say, two feet, on to the polished surface of a hardened steel anvil. In the case of the ball and anvil, I have found that if the surface of the anvil be coated with a minute quantity of rouge in fine oil, wiped off to leave a slightly dulled surface to receive the impact of the ball, each blow followed by a high rebound, the result will be a well-defined circular space, perhaps $\frac{1}{64}$-inch diameter, in the centre of which is a bright spot showing the unsoiled surface of the polished steel; all these marks are superficial, and can be removed when the surface is cleaned. This goes to show that the steel ball and the steel surface have yielded within this limit of elasticity; hence the rebound to so nearly up to the point from which the ball fell is due to the perfect elasticity of the steel, and cannot be reconciled with any destruction or permanent deformation of the surface. This same result is obtained when globules of sand are driven against the polished hard surface of the vitrified brick. The desirability of the brick established in this manner was sufficient to assure me of the correctness of judgment of the engineers who had selected the brick.

With this prelude I wish to call your attention to the fact that the most recent examination of the invert of the tunnel has shown that no deterioration has taken place; and the same may

FIG. 228.—HYDRAULIC FORGING PRESS.

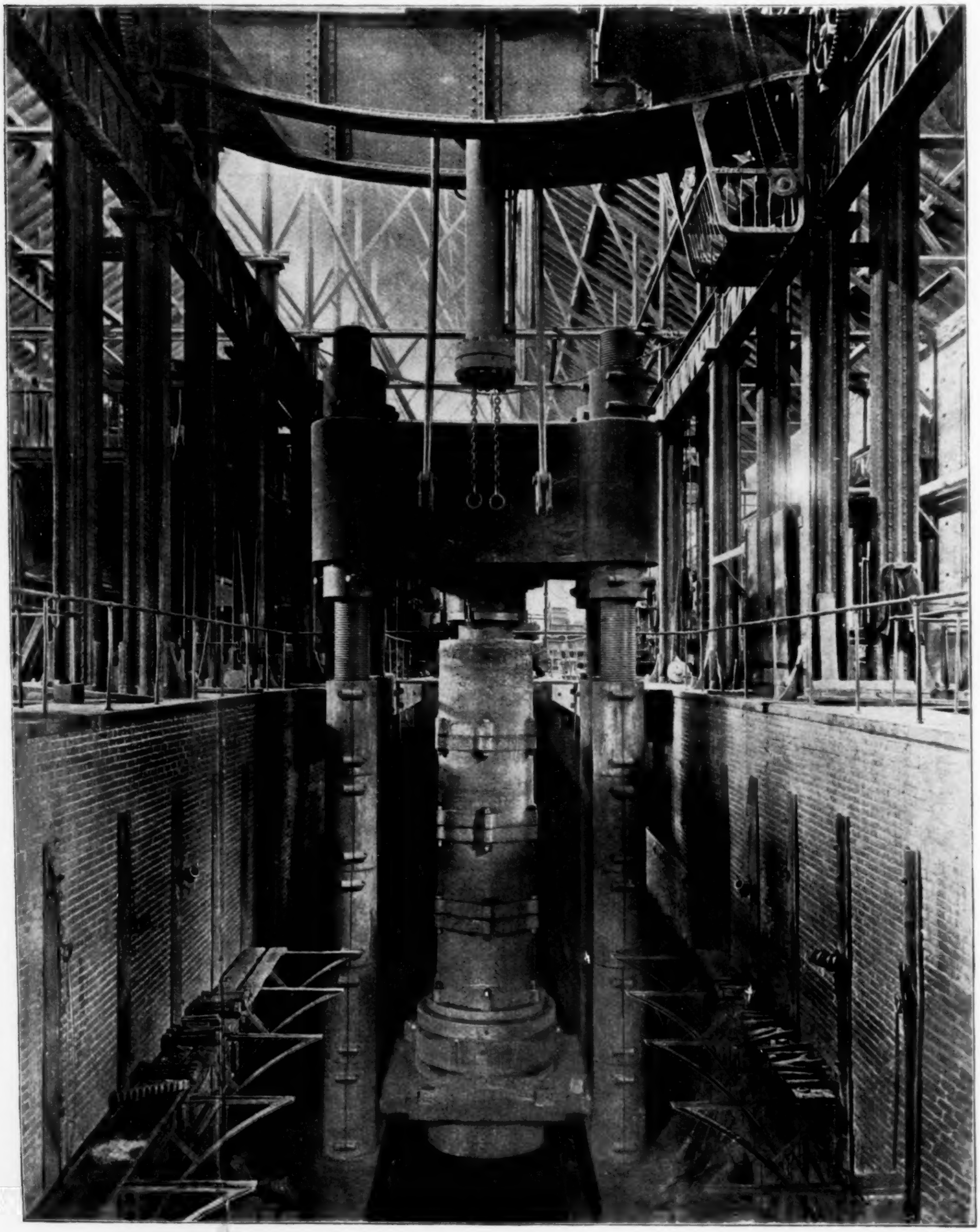


Fig. 229.—Fluid Compression of Steel Ingot in Hydraulic Press.

be said of the bricks forming the side walls. There has been deposited upon the bricks a thin layer of slime, in which coating can be found abundant animal life of the lowest order, small worms and the like. This slime acts as a protective varnish, and we feel assured as to the stability of the brick lining. Had the tunnel been used as a common sewer to receive the discharge from chemical works, the vegetable and animal life now aiding in the preservation of the walls might have been killed, and the surface exposed to what little abrasive matter is carried by the almost clear water of the Niagara River.

As involving an important question in mechanical engineering, I am able to tell you some interesting facts about the forging of the steel field rings which perform so important a function in the 5,000 horse-power dynamo. These rings of nickel steel were the first work done by the great forging press constructed for the Bethlehem Iron Company, under the patents of Sir Joseph Whitworth for forging by compression from steel ingots, which in their turn had been submitted to pressure while the metal was still in a fluid state. The new field rings weighed when finished 28,840 pounds each, and were made from ingots weighing from 116,000 to 118,000 pounds each. Our fellow member, Mr. H. F. J. Porter, kindly loaned me the slides for use on this occasion.

If this great press had not been built, the dynamos as designed could not have been built. By a strange coincidence the size adopted for the field ring was up to the full capacity of the press, and to the utmost capacity of the furnaces built to heat the ingots.

The three rings made for the first machines were somewhat lighter than those made for the five dynamos now in process of erection. To put more metal in the last ring, I decided to use hollow oil-tempered steel shafts for the turbines and dynamos in place of solid steel shafts made for Nos. 1, 2, and 3 units of power. This weight saved in the shafts, added to that of some castings dispensed with, enabled me to name a greater weight of ring in the new specification, so that the heads of the bolts securing the magnets to the ring could be countersunk, thus diminishing the windage at high speed. Fig. 228 shows the press used in forging; Fig. 229, the hydraulic press in which the fluid steel is compressed while cooling to compact the steel and diminish the piping of the metal. The ingots were cast heavy

enough to make three rings from one ingot after the sinking head of the ingot had been cut off. Through the solid ingots a large hole was bored for the mandrel upon which the ring was to be expanded. The process of forging consists of successive expansions and upsetting of the ring, until the proper dimensions as to outside and inside diameter as well as of width of ring have been obtained to allow for rough tooling to the specified dimensions.

In expanding the ring the mandrel forms the lower die or

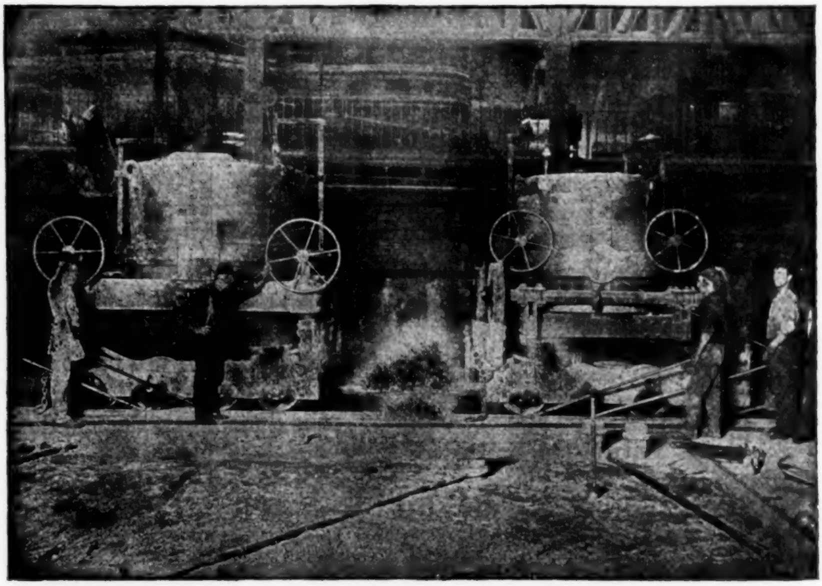


FIG. 230.—LADLES FOR POURING THE INGOTS.

anvil; the mandrel being blocked up on either side of the ring, a powerful ratchet device causes the mandrel to rotate between the compressions. This process is illustrated in Fig. 236.

Fig. 230 shows the ladles used in pouring the ingots; Fig. 231, an ingot with 16-inch holes as drilled to admit the mandrel. Fig. 232 is a field ring partially expanded. Fig. 233 shows the finished forging of the field ring. Fig. 234 shows a hollow ingot being drawn out into a hollow shaft; Fig. 235, the extended shaft which, after being turned, is annealed and then oil-tempered to increase its strength and limit of elasticity.

The steel used in the field rings, when tested for its magnetic properties, was shown to be better fitted for great load than pure iron, such as Lowmoor iron, at the part of the curve at which the excitation is most constant.

You will see when you visit the power house a brick structure called the switchboard. The top carries a platform from which a skilled attendant has command of the dynamos. The switches, new in design, are really placed in the brick chamber below the platform as well as the heavy bus-bars which receive

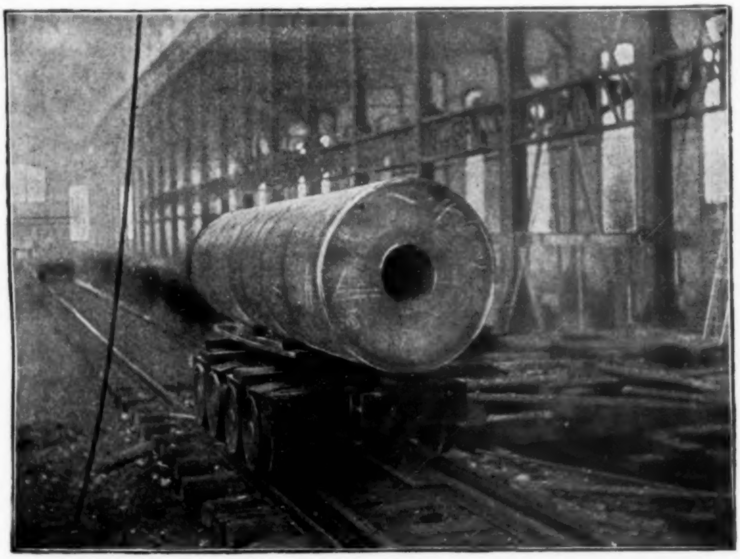


FIG. 231.—INGOT WITH 16-INCH CENTRAL HOLE AS DRILLED.

and transmit the current from the dynamos. It is only thin threads of electricity, as it were, which proceed from the bus-bars and from other parts of the electrical machinery to the instruments of precision which are mounted upon the platform. There is no real switchboard upon this platform. There are cabinets, each of which is devoted to a different purpose, according to the work it has to do; some cabinets controlling the exciting current, others controlling a dynamo. There are other cabinets which control the output of the plant, indicating to which particular establishment the current proceeds—whether to Buffalo or to the manufactories near by. All of these cabinets are

fitted with instruments or attachments which have been designed especially for the peculiar work which is to be done by the Niagara Falls Power Company.

The greatest talent of the technical forces of electrical companies—and particularly of the Westinghouse Electric and Manufacturing Company in this case—has been exerted to per-

FIG. 232.—FIELD RING, AS PARTIALLY EXPANDED.

fect this wonderful aggregation of devices which form the so-called switchboard. This platform is to the work in general precisely what the bridge or conning tower is to the ocean steamers or to the great fighting machines which constitute our navy. It is from the bridge or conning tower that the warship is worked or the passenger steamer directed in its course, and so it is from this platform that the operation of the power house is conducted.

The sluice gates admitting the water to the penstocks of each wheel have never been described in any published paper. As there were no gates obtainable of a design which seemed suitable

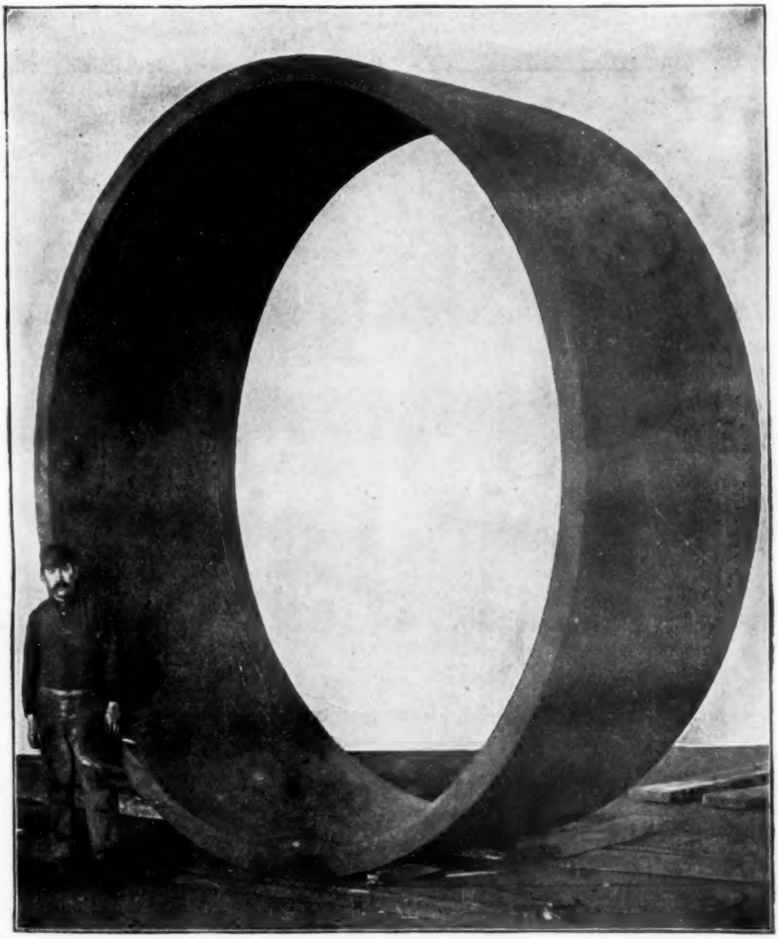


FIG. 233.—FIELD RING.

for this purpose, I recommended the adoption of the Stoney sluice plan as in use in Great Britain, and in some of the large works in Europe. The gates are made of steel, the waterway being 14 feet wide and 12 feet deep. These gates are operated by screws engaging into bronze nuts attached to the gate so that

the screws remain stationary in a vertical position, and the nuts rise and fall with the rotation of the screws. They are so geared as to be readily operated by hand, though in practice the gear-

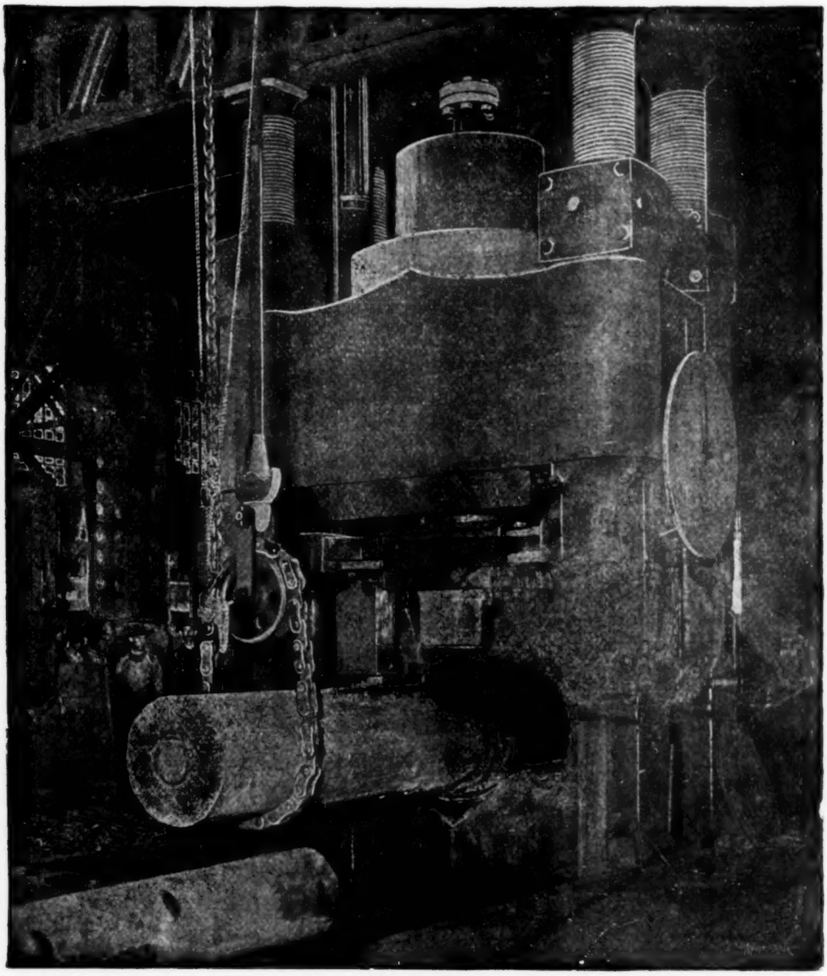


FIG. 234.

ing is driven by an electric motor of about 8 horse-power. The Stoney sluice gate, as you may remember, is provided with a set of rollers between the gate and the guide in which the gate works. These rollers are in a frame hung in loops of chains, one end of

the loop being attached to the moving gate and the other to the stationary framework, so that as the gate rises the rollers move at half the speed of the gate, while the water is prevented from leaking past the gate by strips of rubber which act as packing. The gates have been quite successful, and with the full pressure of 12 feet of water upon them, one man can raise the gate with comparative ease.

The output of the Niagara power plant for the month ending March 31, 1898, was 6,391,000 kilowatt hours. This exceeds

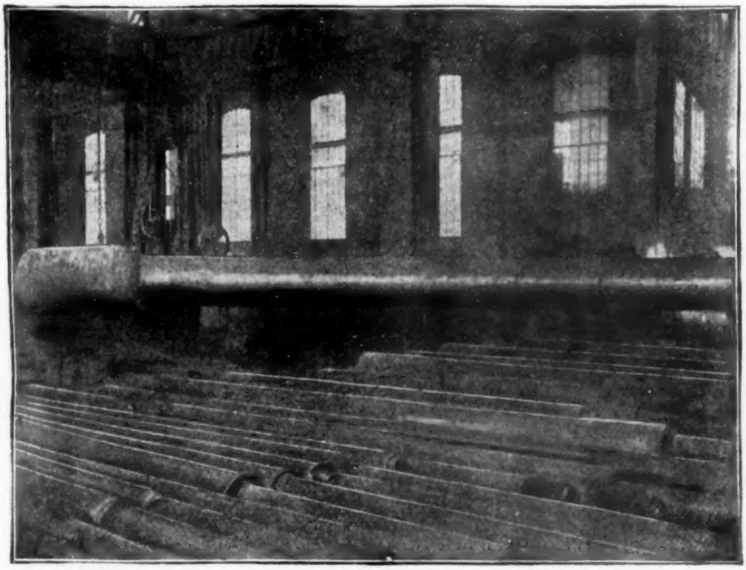


FIG. 235.

the total output of the largest electric plant in Great Britain during the year 1896. In a recent statistical paper read before the British Institution of Electrical Engineers it is shown that the total output of eighty-three of the principal electricity supply companies in Great Britain for the year 1896 was something less than 47,000,000 units. At its present rate of working the Niagara plant in one year exceeds this aggregate by more than 50 per cent.

As to the work that is being done through the output of the dynamos in operation, the great advantage of an alternate

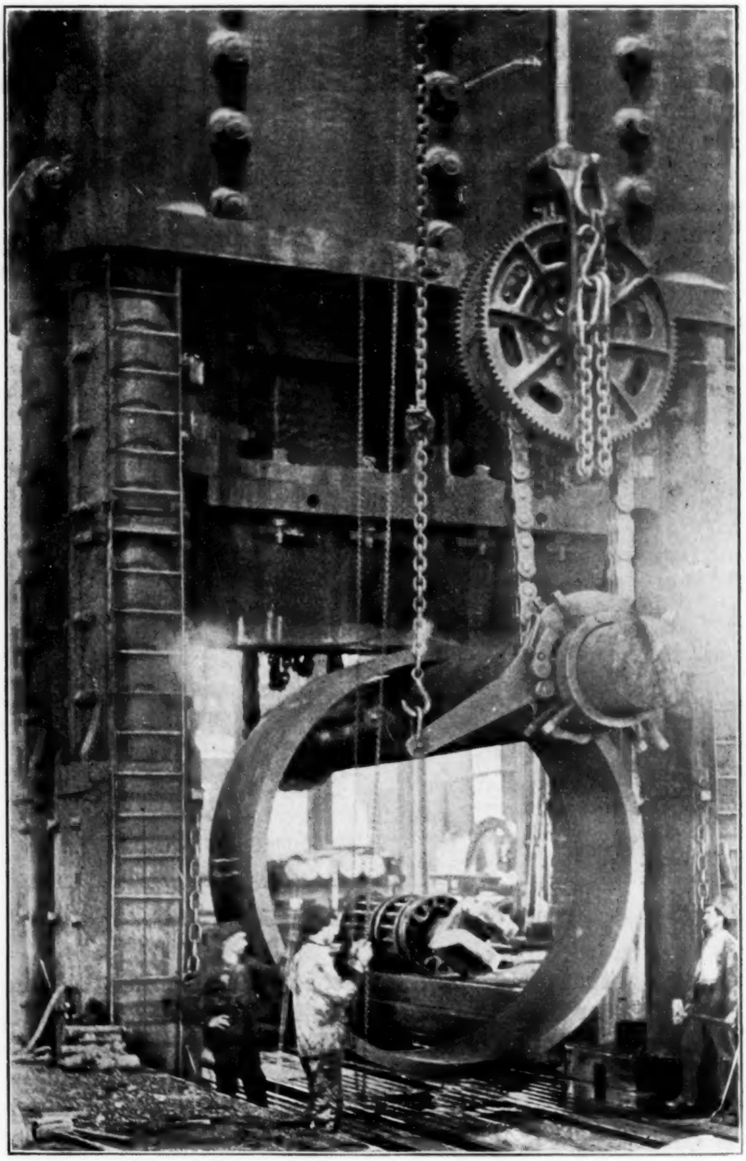


Fig. 236.

current of low frequency is manifested by the character of the various kinds of energy called into play.

In making the new mineral carborundum, as in converting coke into graphite, the alternating current yields heat energy. So also in making carbide of calcium, while for the production of caustic soda and the making of bleaching powder as a by-product from the caustic soda, electrolytic energy is required alone. To extract the metal sodium from caustic soda—both heat energy and electrolytic energy are required; so also in extracting the metal aluminum from the ore of alumina, heat and electrolytic energy require direct current. All these many factories and others not named can be served with the electric current in its best form, while in street railroads, incandescent and arc lighting, and motors of all kinds, direct current or alternating current can be supplied as required.

The Cataract Construction Company in this work aimed to utilize the latest achievements in all parts of the world. They had studied the various modes of power utilization which had already been tried. They were familiar with the wire-rope transmission of Switzerland; the high-pressure water service in London, where steam engines and accumulators create the pressure; the high-pressure water power of Geneva, where elevated reservoirs are used; the compressed-air system of Paris, France, and the compressed-air system, also, in Birmingham, England. Direct current electricity in various places had been used for transmitting power on a small scale, but the Cataract Construction Company adopted the alternating current of low frequency, when there was no example in practice to guide them.

As for the size of unit adopted, it is true that in 1890 Faranti was designing engines of 10,000 horse-power, with the expectation of driving dynamos of 10,000 horse-power each to use the alternating current of high frequency, the object being to furnish electricity for lighting purposes. These large machines have never been finished, and work done in 1890 and 1891 has been discarded.

I was sent to Rome in 1890 to study the water-power plant of the Anglo-Roman Company, then being constructed under the direction of Dr. J. Mengarini, where it was proposed to supplement the electrical power generated by steam engines, the steam being created by coke. This coke was the refuse of their gasworks, but to extend their output beyond the capacity of their coke production, they went to Tivoli for a water power, more than 27 miles away from Rome, where a water-driven plant was

erected to transmit the electricity to Rome at a high potential and a single phase. The frequency in this case was 42 full periods per second, the lowest which had then been used and the lowest that could be used to advantage in arc lighting.

In 1892–93 the Westinghouse Company exhibited at Pittsburg a well-worked-out scheme of alternating bi-phase current of 33 full alternations per second, and that company has built the dynamos for the Cataract Construction Company now in use, with only 25 full alternations per second, guaranteeing their high efficiency in every way.

I regret that I find so much to say in so short a time, and fear I have overtaxed your patience, but thank you for your kind attention to my effort to interest you in what has filled my mind for the past eight years. Before leaving you, I will ask you to note when you visit the power house the arrangement of rack recently erected in the canal on the designs of Mr. Brackenridge. By erecting a continuous rack well out in the stream, with removable sections, the question of clear waterway with the minimum of labor has been solved, and means provided to avoid stoppage from anchor ice in winter.

DCCLXXXVIII.*

HENRY BESSEMER.—1813-1898.

BY JAMES DREDGE, C.M.G., LONDON, ENGLAND.
(Honorary Member.)

I.

FOR the second time I have been honored by an invitation from your Society, to present a memorial address on one of its distinguished members. On the present, as on the previous occasion, I feel that my powers are inadequate to do justice to the subject on which you have been good enough to decide that I am qualified to address you.

It was in October, 1890, that you were gathered to do honor to the memory of one of the greatest of America's engineers, the number of whose personal friends and admirers are, alas! growing fewer year by year, but whose fame still remains, and must remain undimmed. I shall have need to refer frequently to the name of Alexander Lyman Holley in the course of this memorial address, for his career and that of Bessemer touched, and ran parallel, for a number of years, and it was Holley, who, after introducing into the United States Bessemer's great invention, imparted to it such a new vigor, that it has grown to-day to overshadow in its industrial results those of the country of its birth.

I do not propose to ask you to listen to an obituary of Sir Henry Bessemer; still less do I wish to attempt any formal biographical history. It would be impossible to do so, within the limits of your time and patience. Moreover, Professor Thurston has already done more in that direction than I could reasonably attempt to-day; his "Life of Sir Henry Bessemer" is indeed an admirable piece of work; the unflattering homage of a great American scientist to a great English inventor.

* Presented by title at the Niagara Falls meeting (June, 1898) of the American Society of Mechanical Engineers, and forming part of Volume XIX. of the *Transactions*.

Another reason why I wish to confine my remarks within relatively narrow limits, is that it is probable, Bessemer's autobiography, which was left practically complete at the time of his death, will ere long be published, and you will find in its pages far more than I could pretend to tell you.

But I think it may be of interest to you, and certainly it is a privilege to me, to attempt to throw into high relief some of the leading characteristics of the man; some of the leading features of his career; some of the chief results of his work. His genius created a new industry, and founded a new age—the age of steel. No doubt, if he had not accomplished this, others would have done so, just as if Holley had never existed, some other American engineer would have been the pioneer of the steel age in America. It happened, however, that the two specialized energies intended to achieve this great industrial revolution, should be recognized by the name signs of Bessemer and of Holley, and when those names are mentioned, we know just what they stand for in the world of progress. At the same time it is a matter for regret that humbler names, belonging to those perhaps forgotten ones whose coöperation did much to insure success, have to be overlooked, but we must be content with the reflection that the victories of peace, no less than those of war, are associated almost wholly with the names of the great leaders.

II.

I approach the subject of this address with feelings far different to those that animated me when I discoursed about Alexander Holley, though nearly ten years had then passed between the time of his death, and the erection of his memorial in New York City.

But the circumstances were so different. Holley was taken from us at an age when his experience was ripe, and his energies —but for the ravages of fatal disease—were undiminished. According to the chances of life, he had many years of useful work before him, and who can say what he might not have accomplished had he been spared. But with Bessemer it was otherwise. He had long passed the limit of three score and ten, and he was an exception to the rule that the years granted beyond that time are years of burden and weariness, for, until the last, his mind was clear, his body active, and his energy and power

FIG. 205.

for work remained remarkable. His autobiography, to which I referred just now, and on the posthumous publication of which he set great store, had kept him closely occupied for some years, until within a few weeks of the end. His life's work long completed, he could look back over a period of twenty-five calm years, to the time when the strife had terminated, and the industry he had created some twenty years earlier, had made his name famous throughout the world; had given new employment to hundreds of thousands of workers; and had revolutionized the conditions of a thousand industries.

Sir Henry Bessemer has passed from us in the fulness of time; he cheerfully gave up a long life marked by activity and usefulness, and blessed near its close with the rare advantage of enjoying the fame he so well deserved, instead of realizing that it would be attached to his name only after his death. Therefore his death calls for few regrets, other than those inseparable from seeing conspicuous landmarks swept away by the inexorable waves of time.

III.

The career of Bessemer was made remarkable from its commencement to its close by his power as an inventor; but it was not as a many-sided inventor that he earned his popular reputation; it was only by reason of the eminently successful process of steel-making which bears his name, and to the development of which he devoted his best years, and most powerful energies, that he is universally known. His energy as an inventor is illustrated by the record of the London Patent Office, a record which I have collected, and reproduce. It shows that he obtained no fewer than 114 patents for a not very wide range of subjects (his few miscellaneous inventions excepted), while two of his most widely used discoveries were never patented at all. And it must be borne in mind that he was not an idle inventor; I mean that he was not one of those who hastily patent ideas as they may occur; on the contrary, every one of his specifications show careful thought, mechanical skill, and the workings of a logical mind. It is true that only one of his patented inventions bore a rich harvest, but that was because circumstances and force of character compelled him to follow one road to success, instead of losing himself in a maze of intricate paths, which led nowhere, as has happened to so many brilliant minds.

IV.

Before I dwell in some detail on the more important inventions of Bessemer, I shall find it convenient to refer to two of those which were unprotected, and which brought him—the one, tardy government recognition, and the other, sufficient fortune to enable him to conduct the long and costly experiments which resulted in the successful manufacture of Bessemer steel. The first of these was the substitution of the clumsy and easily evaded system of government stamps in use until the early thirties, by a simple and now universally adopted device; the second was the manufacture, on a very large scale, and by a process kept secret for nearly forty years, of the Bessemer bronze powder. These things appear simple enough now, when every postage stamp which is made can be detached from its neighbor by means of perforations, and when "gold" paint —Bessemer and otherwise—is made in a score of places. But at the time—now about sixty years ago—they were great inventions, the one the sudden idea of a youthful and brilliant mind, the other the result of patient investigation and business instinct, allied with mechanical genius. These early efforts, together with some others to which I shall also refer, and the authorship of which is practically forgotten, were sufficient indications that a great future awaited the then unknown inventor.

V.

Sir Henry Bessemer was a remarkable illustration of heredity; of that mysterious sequence in Nature, who sometimes makes her great gifts continuous through two, and sometimes, though rarely, through three generations. His father, Anthony Bessemer, was a genius, though probably of the somewhat robuster sort, as better fitted the times in which he lived, when science was chiefly based on speculation, and industries were controlled by craftsmen and not by machinery. Anthony Bessemer was born in London, in the city of London, that is to say, and at a very early age he was taken to Holland, in which country his parents appear to have made their permanent home.

The Dutch surroundings were more congenial than those of London to the boy, the future father of Sir Henry, for there was much engineering work of a kind going on in Holland, in defend-

ing the country from the inroads of the sea, and in wresting more land from its encroachments. Pumping was continuous, all round the coast, but it was not till the end of the century that steam power began to supersede wind. Being sensible people, the parents of young Anthony Bessemer allowed, and indeed assisted him, to follow his inclinations. He was apprenticed to a mechanical engineer, and in due time he took a conspicuous part in the construction and erection of the first steam pumping engine built in Holland; it was employed to drain reclaimed land near Haarlem.

It is interesting to follow the fortunes of the elder Bessemer a little further. His character and his career helped so much to mould the character and the career of his son. Anthony Bessemer must have been a very skilled mechanic; in all probability he was an able engineer. He had also plenty of the spirit of the adventurer, and when he had learned his trade, and could be taught no more by the pumping machinery practice available, he sought a more promising field for his enterprise. He went to seek his fortune in Paris at the age of twenty-one, and that he very early attained high distinction, is shown by the fact that five years later he was elected a member of the French Academy of Sciences; this distinction was bestowed on him for improvements which he had made in the microscope. The promise of this auspicious commencement was amply fulfilled. The London boy of foreign extraction, and Dutch education, sought and found advancement and wealth rapidly, in Paris. I fancy that the genius of Anthony was possibly of even a higher order than that of Henry Bessemer. Mechanics and all the industrial sciences were in their infancy; appliances and tools to give embodiment to invention were but few and crude. At the beginning of the century there were not many who could exchange ideas mechanical and scientific; technical literature may be said not to have existed; the inventor to be successful had of necessity to rely largely on himself to carry out his ideas with his own hands, and with but little outside assistance had to overcome, or to evade, difficulties. There was no cause for wonder that so talented a workman and so keen a thinker as Anthony Bessemer quickly found highly remunerative employment. We find him occupying a prominent position for some years in the Paris mint, and he must have possessed much artistic as well as mechanical skill, since he was largely occupied in

die sinking and engraving. The copying machine—I mean that class of device for reproducing carved or engraved work from an enlarged model—is regarded as an invention of the latter half of this present century. As a matter of fact it is some seventy years older, for the first practical machine of the kind was made and put to work in the Paris mint by Anthony Bessemer. With congenial surroundings, and increasing prosperity, the time passed, and brought him nearer to the crisis when comparative ruin, and flight to England became an imperative necessity. The French Revolution was at hand and with it the overturning for a time of law and order. Now Anthony Bessemer was not only an inventor, an engineer, and, within limits, an artist; he was besides a shrewd business man, who foresaw that it was better to lose part than all, and he transferred such property as he could to England. He had a narrow chance of escape with life, for he had incurred the suspicion of the Patriots, during a brief administration of an almost fatal position forced upon him—the distribution of bread to the surging, maddened, starving crowd of Paris. You know the passage in Carlyle: "And so then shall be Bakers' Queues, by and by, more sharp tempered than ever; on every Baker's door rabbet an iron ring, and coil of rope; whereon with firm grip, on this side and that, we form our Queue; but mischievous deceitful persons cut the rope, and our Queue becomes a ravelment; whereupon the coil must be made of iron chain. Also there shall be prices of grain well fixed; but then no grain purchasable by them; bread not to be had except by ticket from the Mayor, few ounces per mouth daily; after long swaying with firm grip, on the chain of the Queue. And hunger shall stalk direful: and Wrath and Suspicion, whetted to the Preternatural pitch, shall stalk." A charge of stinting those "few ounces" of bread sufficed to drag Anthony Bessemer from his post and cast him into prison, but he evaded his further progress to the guillotine by escaping, how, we are not informed. That he got clear with his life, was fortunate enough; the material loss he suffered could be made good in England. So he came to London, but only for a time, for he ultimately married and settled in the little village of Charlton near Hitchin in Hertfordshire. I do not know any of the reasons which led him to select this spot, but as he lived there many years, it was evidently well adapted to his purpose. He did not retire to a little country village to rust out in inactivity,

but to recommence a busy, and if possible, a prosperous career. It illustrates the many sides of the practical character of this man, that he made this new start by the manufacture of gold chains. Not on the old-established lines, whatever they might have been, which filled the requirements of the time in this direction. He schemed and had made, new machinery for the purpose, and it seems to have answered as well as most of the things to which he set his busy hand. Certainly this trade and probably others, placed him in such a position after a few years, that, with what he had been able to save from the wreck of the revolution, he felt justified in carrying out the idea, that he would devote the rest of his life to purposeless leisure. As if this could have been possible with a man of Anthony Bessemer's temperament.

This period of idleness lasted for about a year, when it became intolerable. Then, starting on a new path, he devoted his energies and ability to the trade of type-founding, which was no new trade to him, as the dies and type-metal alloys which he had produced in France had brought his high reputation. In this new venture his skill, developed in the Paris mint, was turned again to a good purpose, and I can imagine that he must have made many beautiful fonts with his own hands. Here in the old Hertfordshire village, he entered into partnership with Caslon, whose name is still famous as a type-founder, and the business flourished.

The Bessemer-Caslon combination was firmly established, with a factory which we know must have been equipped and organized far ahead of any similar works of the kind, at the time Henry Bessemer was born. That was on January 19, 1813, and Caslon became his godfather.

VI.

As subsequent events proved, the talent and the purposeful energies of the father were born with the son, and were developed from his earliest years by congenial surroundings. The foundry, the small machine shop, the die-engraving studio, were, at the first, his playgrounds, and then his workshop; the stories told by him and his father had all to do with the romance of industry and development of inventions. From the first he lived in an atmosphere of intelligent labor; the secrets of the foundry ceased to be secrets to him long before he understood anything

about the nature of the alloys, the critical points of fusion, or the art of fine casting.

His education, that is, his general education, was only what was afforded by a country village in the first quarter of the century, and by the somewhat better teaching in the adjacent town of Hitchin; his real training was in the Bessemer-Caslon type-foundry. It is somewhat interesting that the trend of his advance through life was, with some exceptions, an extension of the line marked out by this foundry, modified of course by many circumstances, which also subdued the artistic side of his practical nature, inherited from his father, but which never suppressed it. The more one studies the character of father and son, the more clearly it appears that the career of the latter was but a continuation over nearly a century of that of the former. When Henry Bessemer was seventeen years of age, the whole family left Charlton, and settled in the north of London. From that time young Bessemer was practically his own master, the sculptor of his own fortunes, which yet remained concealed in the untouched block of marble. He was well equipped for the struggle. His father's gifts were his, supplemented with some knowledge of his father's experiences; he was a trained workman and a close observer; his mind was stored with all the trade knowledge the Charlton type-foundry could afford; he was ambitious, though with no defined aim as yet; and physically, his strength and endurance seemed inexhaustible. It is no wonder, too, that he quickly found friends, for the charm of manner which made his society delightful during his maturer years and his old age must have existed to some extent in his early youth.

So, as I say, he came to London at the age of seventeen well armed for the battle of life. That was in 1830. First he turned his knowledge of easily fusible alloys and of casting to account, but not in the direction of type-founding. One of his favorite recreations at Charlton had been the production of delicate art-castings from moulds modelled by himself; the reproduction of natural objects, of leaves and flowers, or insects, or lace, in the making of which the originals were burnt out and replaced by the more permanent replicas in metal.

The Italian plaster casts of figures and decorative subjects were very precious to the popular British art-sense at that time, but they were repellent to the better feelings of young Besse-

mer, who, by some means or other, made a connection among these popular artists, and improved their work, earning money at the same time. But his chief success in these first essays lay in the development of his boyish work at Charlton, and ere long he had attained quite a small reputation for his art castings, made and sold, at first, in white metal, but afterwards coated by placing them in zinc trays, in solutions of nitrate and sulphate of copper. Specimens of this early work remain to this day and give evidence that he would have risen to eminence in this branch of industrial art had he followed it, instead of being called to far higher and more important duties.

The following is an extract from an early edition of Dr. Ure's Dictionary of Arts, Manufactures and Mines, referring to Bessemer's early work in copper deposition, apparently the first of its kind:

"The earliest application of this kind seems to have been practised about sixteen years ago, by Mr. Bessemer, of Camden Town, London, who deposited a coating of copper on lead castings, so as to produce antique heads in relief, about three or four inches in size. He contented himself with forming a few such ornaments for his mantlepiece, and though he made no secret of his purpose, he published nothing upon the subject. A letter of May 22, 1839, written by Mr. J. C. Jordan, which appeared in the 'Mechanic's Magazine' for June 8th following, contains the first printed notice of the manipulation requisite for obtaining electro-metallic casts, and to this gentleman, therefore, the world is indebted for the first discovery of this new and important application of science to the use of life."

Before he was twenty, Henry Bessemer had become an exhibitor at the annual exhibition of the Royal Academy, then, and for some years later, held at Somerset House; this brought him further into notice, and helped to make him, for so young a man, very prosperous. But like his father he regarded a step gained only as the foothold for a higher step; there were other means than casting, to produce artistic work of greater utility and wider application. There was stamping; not only in metal, but in card, in leather, and in fabrics; the decoration of many objects of wide application, and therefore possessing large potential profits.

So well was this scheme developed and pushed commercially, that quite a large trade was created, in embossed materials which were made the fashion by bookbinders; in lace papers, which from that time to this have found a large and ever increasing use; in stamped cards, for which a hundred purposes

were found; and for sheet metal covered with raised designs adapted to many decorative purposes. For all this work two essential elements were needed: dies, and suitable presses. The skill and experience of the elder Bessemer, gained when employed in the Paris mint, and inherited by the son, found a new application now, while his mechanical instinct taught him to select the presses most suitable for his purpose; at first fly presses, but afterwards hydraulic.

While following this line of work, which brought him into somewhat prominent notice, so that—as already said—his productions were found worthy of exhibition at the annual show of the Royal Academy, young Bessemer came into contact with some of the officials of Somerset House, the seat of the inland revenue department. It was notorious at that time that frauds on the government were perpetrated to an alarming extent by the repeated use of stamps affixed to deeds. It was estimated that an annual loss of £100,000 was sustained from this cause, and to devise a means for entirely putting a stop to this occupied much of Bessemer's attention. It is almost superfluous to say that he arrived at a solution by the simplest means, that of perforating the government stamps with dates. Now that this evident method has found a hundred uses throughout the civilized world—to safeguard stamps or cheques, and to divide postage stamps, being among the most common—it is a little difficult to realize the importance of this invention. To Bessemer it meant, in anticipation, vast things: assured fame, a retaining fee of £600 a year as a government official, and a great advance on the road to fortune. In reality, it meant nothing, for though the invention was at once adopted, the official promise was forgotten, overlooked probably during a political crisis, and change of government. But whatever the cause, he never received any consideration for the large sums he had enabled the British Inland Revenue to save. Some forty-five years later, when he had earned for himself all the fame he could desire, and when bestowed honors were superfluous, he was knighted for this invention which had been appropriated without the possibility of redress, because he had not protected himself by any patent. How bitterly Bessemer resented this treatment is evident from the tone of the very interesting letter he addressed to the *Times* in October, 1878, shortly before he had received the knighthood, and which I reproduce.

"THE REWARD OF INVENTION.

"*To the Editor of the Times.*

"*Sir*: The letter which you favored me by publishing last week in relation to the refusal of our Government to allow the Grand Cross to be accepted by our countrymen has elicited many kindly and sympathising expressions from private correspondents; but to the mind of one gentleman, I appear to have 'written with some bitterness.' Now, I may plead guilty to such feeling whenever my memory is driven back by force of circumstances to a period when the Government of this country inflicted on me a great and grievous injustice, in exchange for a great and permanent benefit conferred by me on the State.

"Perhaps nothing would tend so much to dispel this morbid feeling as a brief recital of the circumstances to which I refer.

"The facts are briefly these: At the age of seventeen I came to London from a small country village, knowing no one, and myself unknown—a mere cypher in this vast sea of human enterprise. My studious habits and love of invention soon gained for me a footing, and at twenty I found myself pursuing a mode I had invented of taking copies from antique and modern basso-relievos in a manner that enabled me to stamp them on cardboard, thus producing thousands of embossed copies of the highest works of art at a small cost. The facility with which I could make a permanent die, even from a thin paper original, capable of producing a thousand copies, would have opened a wide door to successful fraud if my process had been known to unscrupulous persons, for there is not a Government stamp or the paper seal of any corporate body that every common office clerk could not forge in a few minutes at the office of his employer or at his own home. The production of a die from a common paper stamp is the work of only ten minutes; the materials cost less than a penny. No sort of technical skill is necessary, and a common copying-press or letter-stamp yields most successful copies. There is no need of the would-be forger to associate himself with a skilful die-sinker capable of making a good imitation in steel of the original, for the merest tyro could make an absolute copy on the first attempt. The public knowledge of such a means of forging would, at that time, have shattered the whole system of the British Stamp Office, had I been so incautious as to allow a knowledge of my method to escape. The secret has, however, been carefully guarded to this day.

"No sooner, however, had this fact dawned on me than I began to consider if some new sort of stamp could be devised to prevent so serious a mischief. During the time I was engaged in studying this question I was informed that the Government were themselves cognizant of the fact that they were losers to a great amount annually by the transfer of stamps from old and useless deeds to new skins of parchment, thus making stamps do duty a second or third time, to the serious loss of the revenue. At a later date this fact was confirmed by Sir Charles Presley, of the Stamp Office, who told me he believed they were defrauded in this way to the extent of probably £100,000 per annum. To fully appreciate the importance of this fact, and realize the facility afforded for this species of fraud by the system then in use, it must be understood that the ordinary impressed or embossed stamp, such as is employed on all bills of exchange, if impressed directly on a skin of parchment, would be entirely obliterated if the deed be exposed for a few months to a damp atmosphere. The deed would thus appear as if unstamped, and, therefore, invalid. To prevent this it has been the practice, as far back as

the reign of Queen Anne, to gum a small piece of blue paper onto the parchment; and to render it still more secure a strip of metal foil is passed through it, and another piece of paper with the printed initials of the sovereign is gummed over the loose ends of the foil at the back. The stamp is then impressed on the blue paper, which, unlike parchment, is incapable of losing the impression by exposure to a damp atmosphere.

"But, practically, it has been found that a little piece of moistened blotting-paper applied for a whole night so softens the gum that the two pieces of paper and the slip of foil can be removed from the old deed most easily and be applied to a new skin of parchment, and thus be made to do duty a second or third time. Thus the expensive stamps on thousands of old deeds of partnership, leases, and other documents, when no longer of value, offer a rich harvest, to those who are dishonest, to use them.

"With a knowledge of these facts I was enabled to fully appreciate the importance of any system of stamps that would effectually prevent so great a loss to the Government; nor did I for one moment doubt but that Government would amply reward me if I were successful in so doing. After some months of study and experiment—which I cheerfully undertook, although it interfered considerably with the pursuit of my regular business, inasmuch as it was necessary to carry on the experiments with the strictest secrecy, and to do all the work myself during the night after my people had left work—at last I succeeded in making a stamp that satisfied all the necessary conditions. It was impossible to remove it from one deed and transfer it to another. No amount of damp, or even saturation with water, could obliterate it, and it was impossible to take any impression from it capable of producing a duplicate.

"I knew nothing of patents or patent-laws in those days, and if I had for a moment thought it necessary to make any preliminary conditions with Government I should have at once scouted the idea as one utterly unworthy. Dealing direct with Government, I argued, must render my interests absolutely secure; and in this full confidence I wended my way one fine morning to Somerset House, and was ushered into the presence of the chief, Sir Charles Presley. I explained the object of my call, and showed him by numerous proofs in my possession how easily all his stamps could be forged, and also my mode of prevention. He was greatly astonished at what I had communicated and shown to him, and asked me to call again in a few days, which I did, and after further conversation on the subject, he suggested that I should work out the principle of my invention more fully. This I was only too anxious to do; and some five or six weeks later I called on him again with a newly-designed stamp, which greatly pleased him. The design was circular, about 2½ inches in diameter, and consisted of the Garter, with the motto in capital letters, surmounted by a crown. Within the Garter was a shield, with the words 'five pounds.' The space between the shield and the garter was filled with network in imitation of lace. The die had been executed in steel, which had pierced the parchment with more than four hundred holes, each one of the necessary form to produce its special portion of the design. Since that period perforated paper has been largely employed for valentines and other ornamental purposes, but was previously unknown. It was at once obvious that the transfer of such a stamp was impossible. It was equally clear that mere dampness could not obliterate it; nor was it possible to take any impression from it capable of perforating another skin of parchment.

"This design gave great satisfaction, and everything went on smoothly; Sir Charles again consulted Lord Althorp and the Stamp Office authorities determined

to adopt it. I was then asked if, instead of receiving a sum of money from the Treasury, I should be satisfied with the position of Superintendent of Stamps, at some £600 or £800 per annum. This was all I could desire, and great was my rejoicing over the prospect before me, for I was at that time engaged to be married, and my future position in life seemed now assured. A few days after affairs had assumed this satisfactory position, I called on the young lady to whom I was engaged (now Mrs. Bessemer) and showed her the pretty piece of network which constituted my new parchment stamp. I explained to her how it could never be removed from the parchment and used again, mentioning the fact that old deeds with stamps on them, dated as far back as the reign of Queen Anne, could be fraudulently used, when she at once said, 'Yes, I understand this; but surely if all the stamps had a date put upon them they could not at a future time be used again without detection?' This was, indeed, a new light, and, I confess, greatly startled me, but I at once said the steel dies used for this purpose can have but one date engraved upon them. But after a little consideration I saw that moveable dates were by no means impossible; and shortly after it came into my mind that this could easily be effected by drilling three holes of about a quarter of an inch in diameter, in the steel die, and fitting into each of these openings a steel plug or type with sunk figures on their ends, giving on one the day of the month, on the next the month of the year, and on the third circular steel type, the last two figures of the year. I saw clearly that this plan would be most simple and efficient, would take less time and money to inaugurate than the more elaborate plan I had devised; but I must confess, that while I felt pleased and proud at the clever and simple suggestion of the young lady, I saw also that all my more elaborate systems of piercing dies, the result of months of study, and the toil of many a weary and lonely night, was shattered to pieces by it, and I more than half feared to disturb the decision that Sir Charles Presley had come to as to the adoption of my perforated stamp; but with my strong conviction of the advantages of the new plan I felt in honor bound not to suppress it, whatever might be the result. Thus it was that I soon found myself again closeted with Sir Charles at Somerset House, discussing the new scheme, which he much preferred, because, as he said, all the old dies, old presses, and old workmen could be employed, and there would be but little change in the office, so little, in fact, that no new superintendent of stamps was required, which the then unknown art of making and using piercing dies would have rendered absolutely necessary. After due consideration my first plan was definitely abandoned by the office in favor of the dated stamps, with which every one is now familiar. In six or eight weeks from this time an Act of Parliament was passed, calling in the private stock of stamps dispersed throughout the country, and authorising the issue of the new dated ones.

"Thus was inaugurated a system that has been in operation some forty-five years, successfully preventing that source of fraud from which the revenue had so severely suffered. If anything like Sir Charles Presley's estimate of £100,000 per annum was correct, this saving must now amount to some millions sterling; but whatever the varying amount might have been, it is certain that so important and long established system as that in use at the Stamp Office would never have been voluntarily broken up by its own officials, except under the strongest convictions that their losses were very great, and that the new order of things would prove an effectual barrier to future fraud.

"During all the bustle of this great change, no steps had been taken to install me in the office. Lord Althorp had resigned, and no one seemed to have author-

ity to do anything for me; all sorts of half promises and excuses followed each other with long delays between, and I gradually saw the whole thing sliding out of my grasp. Instead of holding fast to my first plan, which they could not have executed without my aid and the special knowledge I had acquired, I had in all the trustfulness of youthful inexperience shown them another so simple that they could put it into operation without any assistance from me. I had no patent to fall back upon. I could not go to law, even if I wished to do so, for I was reminded when pressing for mere money out of pocket, that I had done all the work voluntarily and of my own accord. Wearied and disgusted, I at last ceased to waste time in calling at the Stamp Office, for time was precious in those days, and I felt that nothing but increased exertions could make up for the loss of some nine months of toil and expenditure. Thus, sad and dispirited, and with a burning sense of injustice overpowering all other feelings, I went my way from the Stamp Office, too proud to ask as a favor that which was indubitably my just right; and up to this hour I have never received one shilling or any kind of acknowledgment from the British government. Such has been my reward.

"I am, Sir, your obedient servant,

"HENRY BESSEMER.

"DENMARK HILL, *October* 29, 1878."

Some years after this great disappointment, Bessemer became a prolific patentee, but for the present his mind and energies had run in the fruitful channel of special and secret processes.

VII.

We have seen how young Henry Bessemer came to London at seventeen years of age with very limited means and unlimited ambition, and, in anything but biographical fashion, we have sketched some of the events of the three or four eventful years that followed. Shortly after his arrival in London he made the acquaintance of a Mr. Allen who resided in Camden Town, a northern London suburb, as you all know. This apparently simple incident was to be followed by results undreamed of by the quiet family, which included a number of children, when they accepted their young friend as a visitor. Between this family and Bessemer, as time went on, the closest relations grew. Add to this the fact that a near neighbor and friend named Longsdon had four sons, and the elements were assembled which, by later combinations, helped to assure the success of the Bessemer process. It is a very commonplace story, one which repeats itself daily in every large city, but which does not bear great results many times in a century. Bessemer was happily fated to marry one of the Allen daughters, and Robert Longsdon to marry another; in due time one young Allen

(Richard) was to run, for nearly forty years, the secret process of the Bessemer bronze powder which was to help find the money wherewith the experiments in steel-making were to be carried out. Also in the fulness of time, Bessemer and Longsdon (the latter partly from ability and partly because he possessed a certain amount of capital) were to become partners prior to and during the years of the great steel harvest. And later, another of the Allen boys (William Daniel) was, after he had left school, to become the confidential assistant of his brother-in-law Bessemer, who was eleven years his senior, and afterwards to be the head of Bessemer & Co. of Sheffield. There are many of you who knew personally the late W. D. Allen, and those who did, loved and honored him for himself, and respected him as a famous steelmaker. Incidentally it may be mentioned that another Longsdon (Alfred) followed the way led by Bessemer, found himself ultimately the representative of Krupp, of Essen, in England. So the course of many lives was changed by the simple accident of a chance acquaintance.

When the unfortunate episode of the stamp-perforating device occurred, Bessemer had advanced far on the path of courtship, and the disappointment, due to broken official faith, must have been doubly severe, for it gave a death blow to the immediate fulfilment of his wishes, though it stimulated him to fresh endeavor.

VIII.

Until long after 1831 the sole supply of plumbago suitable for drawing pencils came from a single mine in Cumberland, in the parish of Borrowdale. I am speaking of the supply for Great Britain, of course. It was a veritable treasure house this mine, guarded close always, and opened but for a few weeks every year, when a small quantity of the precious mineral—some 30,000 or 40,000 pounds weight—was extracted, and the mine was again sealed. The plumbago was bought chiefly by a Jewish ring, for about 45s. a pound, and by them it was converted into drawing pencils. But the ring was dependent on an inner ring, the plumbago cutter, who with great skill, with 60 per cent. of waste, and for 21s. a pound, sawed the brittle stuff into thick sticks. The waste only realized 2s. 6d. a pound, so there was no wonder pencils were expensive, for the sticks, when ready to go inside their cedar sheaths, brought £4 10s. a pound. Here

was an admirable chance for young Bessemer; he had only commercial men to deal with, not government officials, so he knew just where he was. First he designed and had made a hydraulic press which would exert a pressure of 400 tons (I do not know the pressure per inch); then he bought up all the plumbago dust to be had in London at 2s. 6d. a pound; afterwards, growing bolder, he, with a friend, repaired to Borrowdale, where he made a corner in plumbago dust at highly pleasant prices.

So he made sure of his supply, which, being properly ground, lixiviated, and mixed with some binding material, was subjected to the action of his 400-ton press. Thus he obtained compact slabs, which he afterwards cut into sticks with a very fine saw which did not produce much waste, and he was able to undersell the market beyond competition. This is undoubtedly the first instance of artificial lead-pencil making in England; it is not a little remarkable that so fertile a brain as his should not have conceived the notion of squeezing his plastic mass of plumbago through a die; that idea, however, was to be reserved for some one else in a future generation. This pencil-making business lasted for a time, and while bringing in some profit it helped him further on towards success. Ultimately he sold his secret for £200.

The story of the Borrowdale plumbago industry is so curious that I give here an extract from Lyon's *Magna Britannia* (1816) referring to the subject:

"At the head of Borrowdale on the side of a very steep mountain is the celebrated mine of wadd or black lead. The demand for this article being limited, the mine is only opened occasionally, so as to answer that demand. As this is a substance which does not require any mechanical process to prepare it for use, great care is taken to secure it from plunder. The mine is only accessible through the agent's house which is built over it. In consequence of the ease with which depredations on this property might be committed, an act of parliament was passed in the year 1752 to secure the property, by subjecting the stealer and the receiver to the same punishment as for felony. In the preamble to this act the black lead is described as necessary to the casting of bomb-shells, round shot, and cannon balls; its chief use is now for making pencils; the coarser sort is employed in the composition of crucibles and for giving a black polish to iron. The wadd or black lead is not found in regular veins, but lying in lumps or nodules in the fissures of the slate-rock, the lumps varying in weight from an ounce or less upwards of 50 pounds. When the mine is opened, a sufficient quantity is procured to answer the demand for several years; the black lead of the best quality is packed in barrels and sent to London by wagon, the proprietor of which is bound in a considerable sum for its safe delivery. It is then deposited in the cellars under the Unitarian Chapel in Essex Street, and on

the first Monday in every month there is a sale of it in an upper room of a public house in the neighborhood. The pencil makers attend, and selecting pieces of the best quality, purchase according to their respective wants. The coarse sort is afterwards sold for other purposes. About £3,000 worth of the black lead is sold in a year; the price of the finest quality is 35s. per pound; of the coarser, £120 per ton.

"Of late there has been some alarm as to the failure of this useful article; it is nearly four years since any quantity has been procured; only three or four barrels were procured in 1814, but we are informed that they have now better prospects. One-half of the mine is the property of Henry Bankes, Esq., M. P., the other half is held by several proprietors under a lease for a long term of years, originally made by Heperson, who in conjunction with Mr. Bankes's ancestor, had a grant from the Crown."

In Ure's *Dictionary of Arts, Manufactures and Mines* (1860), the following reference is made to the manufacture of pencils, as still followed in England at that date:

"The best black-lead pencils of this country are formed of slender parallelopipeds, cut out by a saw, from sound pieces of plumbago, especially such as have been obtained from Borrowdale in Cumberland—usually enclosed in wood, although of late years used in everpointed pencil cases. Pieces of plumbago sufficiently large to be thus employed are very rare, and the supply from the Cumberland mine can no longer be relied upon. The mine has been closed for some years, but during the past year (1859) a company has been formed for again working it. Many attempts have been made to utilize the smaller fragments of plumbago, as by grinding them, melting them with sulphur and antimony and the like, but few have been attended with success. The late Mr. Brockender was long occupied in seeking some method. He powdered and compressed the plumbago, but could not make the material adhesive. He succeeded to some extent by exhausting air, and then compressing small sticks of the material."

The description of the pencil works at Keswick as described in *Chambers' Journal* (1848) is also so graphic and correct, that we do not hesitate to transfer more to these pages:

"The factory consists of a house of several stories in the lower of which is a huge water wheel turned by the Greta River. Timber is cut to shape, and plumbago is tested for hardness and quality. Pieces are glued to a board, and then sawn into thin slices. The slices are handed to the fitter, who sticks the pieces into the grooved rods in front of him, and snaps off the slice level with the surface, leaving the groove properly filled. In the making of a single pencil, perhaps as many as three or four slices are required. The sides of the sticks are covered up and are ready for rounding, after being cut to lengths by circular saw."

IX.

Henry Bessemer married at a very early age—at twenty-one or thereabouts, I believe—and I may dismiss this all-important

event of his life with the remark, that, unlike so many early marriages, his proved in all ways a happy one, and that it lasted almost for the rest of his long life, Lady Bessemer having died only a few months before her husband.

With new, and, we may be sure, joyfully accepted responsibilities, Henry Bessemer's energies forced him into fresh ventures, all based on the previous undertakings which had proved so successful. The hydraulic press, which had been kept busy in the compression of plumbago dust for making pencils, suggested to him a new use : its application to the industry his father had so long conducted at Charlton. To cast type under pressure, having first exhausted the air in the moulds, was the subject of his first patent, No. 7,585, dated March 8, 1838, and called "Machinery for casting type." This proved fairly successful, and, among other places, a plant was established at Edinburgh, where young W. D. Allen was sent to superintend its installation.

The invention is interesting as being probably the first recorded in the British Patent Office for casting under pressure. At this time, too, the industrial art side of his character found practical application in the work of engine turning, the well-known Jacob Perkins having furnished him with an engine-turning lathe. With this he executed a great deal of work with his own hands, one of his best customers being Mr. De La Rue, founder of the famous stationery business, and who, like his son, was a man of science. The connection arose out of the fly-press embossing work already referred to, Bessemer having found a ready sale for this class of decorative work with the stationery firm. Later on we shall see how this acquaintance brought about one of these insignificant incidents on which success often depends.

While busy with all these various matters, which kept him in comfort till greater things should come, Bessemer found time to invent a type-composing machine, the practical value of which was proved by its being used in the printing office of one of the few penny weekly magazines then existing; it could set 5,000 type an hour. For some reason this machine was never patented, nor does it appear to have found any application, excepting in the offices of the *Family Herald*. Its interest, therefore, is purely historic, an evidence of the ingenuity of the fertile inventor.

It was about this time, also, that he devised a cheap means of imitating Utrecht velvet, by a modification of his embossing process; this was introduced with very considerable success and profit. We shall have occasion later on to refer to this invention, which formed the subject of a patent some years after.

The busy hands and fertile brain had enabled their owner to amass considerable funds before he was thirty; what fortune he then had was the result entirely of personal labor, for he did not gather royalties from his earliest patents; in fact, his name appears on the Patent Office register only three times prior to 1843, when he filed his first specification for making bronze powder. Probably the type-founding under pressure brought him some return; but his device for stopping railway carriages died still-born, while his process for making glass proved scarcely profitable. In fact, it may be concluded that, with the exception of the long series of steel-making patents, few of Bessemer's protected inventions were a source of income.

X.

Prior to the time when Bessemer turned his attention to the production of "bronze" powders the manufacture was a German monopoly; the material, which was produced by a secret process, found a large and highly profitable market all over the world as a basis for metallic paint. It commanded a relatively enormous price—many pounds sterling per pound.

The material of which it was composed was comparatively worthless; the value lay in the art of a long and tedious manufacturing process, and in the monopoly. To destroy this, and to produce an equally good article at a price which could defy competition, was a problem, the solution of which was one entirely to Bessemer's mind. Having attacked it, he was not the man to be content with anything but complete success. And he achieved it, but not until his patience was almost exhausted, and his means straitened. The patent which he obtained in 1843 gives an indication of the way, but not the method he pursued. For some time he encountered only unqualified failure. He had designed and made special machinery for disintegrating and reducing to an impalpable powder the alloys which he employed. As a basis for a pigment the material was satisfactory; as a painted surface it was an absolute failure, possessing no

brilliancy, no suggestion even of metallic lustre. The time and money spent in designing and making his machinery were time and money wasted; he had learnt only that success could not lie upon the path he had followed.

He was discouraged, almost prepared to admit defeat, and to regard his efforts and his outlay as so much dead loss. And there is no doubt he would have given up but for one of those slight accidents which have all-important consequences. I have said that his acquaintance with the De La Rues had been formed through his business relations; that he supplied them with embossed card and metal, and executed much engine-turning work for them. One day he called on Mr. De La Rue, and found him busy with a microscope; he was examining samples of flour and of potato starch, and he explained to Bessemer how he could detect the difference between them by the form of their crystals. The hint sufficed; if the source of starch could be thus decided, why not the difference between his useless grains of bronze powder and those made in Germany. The microscope did give up the secret of the German monopoly; it showed that while the grains of his (Bessemer's) paint were round and uniform, those of German origin were in very thin flakes of irregular shape.

It was necessary therefore to roll the metal into the thinnest sheets possible before breaking it up into minute particles, and not to grind it into powder. With this information the rest was comparatively easy, only it was necessary to throw on one side all that had been already done and to commence afresh. New machinery, new experiments, and this time success so complete that the net price of the paint could be reckoned in shillings as compared with the German selling price in pounds. But Bessemer was far too good a man of business to spoil the market; on the contrary, he kept only well below all competition, which followed him down to the ultimate loss, by Germany, of the market. Competition was, indeed, quite out of the question, for though the German product had carried a heavy profit, the means of production were slow and costly. The sheets of alloy were hammered out thin by hand, like beaten gold. Bessemer, on the contrary, rolled his metal by machinery at a nominal cost, while the subsequent processes were equally cheap, simple, and efficient.

Being of a shrewd and secretive mind he patented no details

of his plant, but determined to work it as a secret process in a small factory in London. It is strange that he was enabled to do this for nearly forty years; during at least half this time the industry brought in quite large revenues, putting him at his ease, if not making him rich. Very slowly the method which had sprung from his genius was elaborated by duller minds until at last the secret had fully served its turn and it was not worth while to continue the industry, but that was not until the selling cost had fallen to one-twentieth of what it had been before Bessemer entered the market.

I have spoken of the Allen family, one member of which became Lady Bessemer. To the eldest brother, Richard, Mr. Bessemer entrusted the entire management of the factory so soon as it was in running order, and these two, with one or two loyal mechanics, conducted the business, which was largely automatic. Naturally the German manufacturers were furious at this sudden and unexpected attack on their monopoly, and during some years they were unceasing in their efforts to learn the secret of their undoing. But Bessemer consistently refused to consider any negotiations, until, wearied with fruitless efforts to gain their end by direct means, his competitors sought devious ways with no better success. The little factory was watched day and night as eagerly as if it had been an Anarchist head centre, and no pains were spared to corrupt the small band of faithful employees. Sir Henry in later years would tell with much delight the story of one specially persistent attempt. The German agent, spy, or what you will, sought to get information from the old Scotch engine driver of the factory, who at once reported to Mr. Bessemer, and asked for instructions. "Tell him," said Bessemer, "that you have spoken to the engineer who designed all the machinery, and that he will see you and give you information for a consideration." The appointment was made, the engineer being Bessemer himself, and the place his own house near by. With much assumed perturbation on his part, and unlimited promises on the other side, the faithless "engineer" was induced to show the working drawings of the machinery, nay more, to give facilities for tracing them, which was done at express speed. Then the emissary departed with further promises that the treachery should be handsomely rewarded. Each side was well pleased with the negotiations, for the plans taken over to Germany were those

of the machinery that had resulted in total failure. Some years later Bessemer, being in Germany during one of his very rare visits abroad, found himself in the city where the factory was situated, from which the easily beguiled agent had come. Anxious to learn if possible the result of his practical joke he called on the manufacturers, and the nature of his reception left him in little doubt about his success. Any uncertainty, indeed, which might have remained was dispelled a few hours later, when he was arrested in his hotel on some allegation emanating from the manufacturers aforesaid, and was involved in no little trouble before he was liberated by the efforts of the British consul and other officials. I have often heard Sir Henry Bessemer tell that story in a way that showed it still remained a very pleasant memory.

XI.

I referred just now to the process Bessemer devised for the production of imitation Utrecht velvet, a process which he worked himself for some years with considerable profit, until in fact the price realized fell below the margin which made it worth his while to continue the industry. The story of this incident in his life is told far better than I could tell it, in the following letters, the second of which was written about a year before Sir Henry's death, under the following circumstances. A fragment of the velvet came into the possession of a friend of the family—Sir William Bailey, of Salford—who sent it, with the accompanying letter, to Mrs. Charles Allen, a niece of Sir Henry:

". . . Please receive herewith by pattern post a piece of embossed velvet with which Sir Henry Bessemer had to do when a young man.

"I am sorry I cannot give dates, but it must be between thirty and forty years ago that Mr. Pugin the eminent architect was engaged to design the draperies of the House of Lords, and he designed this pattern velvet, Sir Henry Bessemer designing and engraving the rollers for embossing it. I obtained it from Mr. Lamb, who knew Miss Bessemer (Sir Henry Bessemer's sister) well.

"He informs us that Miss Bessemer was also clever as a designer, and had to do with the embroideries of St. George's Chapel and Windsor Castle, Miss Bessemer being one of the first to introduce art needle-work as an industry for ladies, into London.

"Some very beautiful work was executed by Miss Bessemer's staff, and amongst it some of the tapestries at Chatsworth Hall. The Devonshire Banner, with the Devonshire Arms richly emblazoned in beautiful colours now in the Hall, was executed under Miss Bessemer's superintendence by the staff of ladies. . . ."

Mrs. Allen sent half of the interesting relic to Sir Henry Bessemer, and in acknowledgment received the following very characteristic letter, which contains some curious details on the subject of the bronze powder, as well as the velvet industry.

"DENMARK HILL, LONDON, S. W., *March* 31, 1897.

"MY DEAR NIECE: Allow me to thank you very much for the most interesting specimen of embossing in Utrecht velvet which you have been so kind as to send me; it brings back old remembrances that will be for ever dear to me.

"My sister was an artist of more than average ability in water colour drawing, and excelled greatly in the art of embroidery in silk, and in due course was appointed embroideress to the Princess Victoria before she became Queen.

"It is rather curious that I seemed born with an instinctive taste for designing patterns, and when I reflect on my natural aptitude for mechanical inventions, this old power of designing foliage, and flowers, but more especially grotesque ideal scroll work and foliage, it seems to me to have been as a sort of faculty of inventing unseen forms in almost endless variety, and when I was only eighteen, I designed for one year the principal Indian patterns for the great Indian silk merchants Everingtons of Ludgate-Hill. It is a curious fact in connection with your friend's letter that I designed the patterns embroidered by my sister, in the draperies of the beautiful cradle of her Gracious Majesty's first infant, at which early period I had the honour to be an exhibitor, together with my sister, at the Royal Academy, then held at Somerset House in the Strand.

"My sister had made a great number of flower paintings which she put together in a portfolio she had made, and on which she asked me to write in bold printing letters, 'Studies of Flowers from Nature by Annie Bessemer.' This little incident shaped my whole future life. I thought I would write the inscription in gold letters, and ordered two ounces of bronze powder (called also gold powder) but which is really only a beautiful fine brass, intrinsically worth eight pence per pound. I was charged fourteen shillings for my two ounces of brass powder, with the result that a material known and used in China and Japan for more than 1,000 years, was still made by a roundabout hand process, hence its great cost. I invented an elaborate series of self-acting machines and manufactured it successfully. My first order was obtained by my traveller, from the Colebrookdale Iron Company, for two pounds at eighty shillings per pound net. I kept the process a profound secret for about thirty-six years; it furnished me the money necessary for pursuing my many patented inventions, and then the secret leaked out, prices went down and down until I was selling the same article for which I had eighty shillings a pound, as low as two shillings and ninepence, when I gave up the manufacture.

"But I am letting my pen run away with me, and forgetting all about Utrecht velvet. Between forty and fifty years ago, I was exhibiting some specimens of castings from natural objects, cast in white metal and which were coated by a thin film of copper deposited thereon from an acid solution of that metal. The Exhibition was known as 'Toblisses'' Museum of Arts and Manufacture, which occupied the site of the present National Gallery in Trafalgar Square.

"These specimens were seen and admired by Mr. Pratt, an upholsterer in Bond Street, and he sought me out, showing me a beautiful piece of velvet work of French manufacture; he proposed to produce a similar effect by embossing Utrecht velvet. He had tried the embossers of cotton velvet at Manchester but

they had utterly failed. This stubborn pile would not keep down, and the pattern was all gone in a few weeks.

"I studied the question both from a chemical and a mechanical point of view, made some experiments and found that my plan was successful. The simple fact is that wool, like the hair of all animals, partakes of the property of horn, and is fusible by heat, but that high temperature is destructive if continued for more than a second of time, and my rollers would burn the whole fabric if worked too slowly. There were many details to work out, and when that was done I constructed the necessary machinery at my own cost, and managed to have six shillings a yard for all the velvet I passed through the machine. The first work done by the machine was for the furnishing of a suite of rooms in Windsor Castle. With this good introduction the material became popular and fashionable, and I may add profitable. I increased the demand by lowering the price, and when it got down to one shilling per yard, I sold the machinery to a manufacturer of Utrecht velvet, at Danbury; the price eventually came down to twopence per yard, and then omnibusses and cabs were lined with it. My great difficulty was, I could find no one capable of preparing the rolls, and had, as a last resource, to do it myself. . . .

"Your affectionate Uncle,

"HENRY BESSEMER."

It is worth noting that some years after he had disposed of his process, Sir Henry obtained a patent for casting embossed cylinders for stamping velvet and other fabrics.

As I have said before, only one patent was taken by Bessemer in connection with his bronze powder industry. It is dated June 15, 1843, and is called "Certain improvements in the manufacture of Bronze and other metallic powders." The specification states that: "The metal or alloys of metal should be first reduced to very thin leaf, so that one pound may extend over about 850 superficial feet. The leaf is extended upon a sieve, olive oil is poured thereon and forced with the leaf through the sieve, and both are mixed and ground in a suitable grinding machine. The oil is afterwards pressed out from the metallic powder by putting it in bags, and subjecting it to the action of a hydraulic press. The residue is allowed to crumble and is reduced to the conditions of bronze powder."

XII.

The bronze paint industry being established on a sound commercial footing, and its management entrusted to capable and loyal assistants, Bessemer found time to devote to other matters besides the production of stamped Utrecht velvet, and a variety of miscellaneous work. He turned his attention to processes in

the production of glass, and more especially to the manufacture of sugar, and he labored at the latter from 1845 to 1853, when more important problems claimed his attention. Between these years he obtained a number of patents for improvements in methods for extracting the juice from the cane, and its subsequent treatment. This work had a certain commercial value at the time, though it possesses only a faint historic interest now. But there is abundant evidence that the active brain of the inventor was concentrated on the subject, and for that reason I must refer to it here. His first patent (Feb., 1849) refers to the use of reciprocating pistons actuated by steam or other motive power, and working in slotted tubes or cylinders, for the purpose of expressing the juice from the cane, previously cut into short lengths, and charged into the tubes. The specification also refers to a method of maintaining the expressed juice at a constant temperature when passing from the press to the defecating vessel.

The second patent (July, 1850) was of much importance in the series. Its full title is "Certain improvements in apparatus acting by centrifugal force in the manufacture of sugar, and other improvements in the treatment of saccharine matters by such apparatus." These improvements treat "of the saccharine juice of the cane immediately after it has been expressed, and in which state it is found mixed to a greater or less extent with small fragments of the cane, and the arrangement of centrifugal filtering apparatus for separating these particles from the juice." After the cane juice was thus filtered "it may be defecated by any of the usual methods now practised, when a certain quantity of coagulated matter will be found suspended in the juice." A centrifugal filtering apparatus was then employed to effect the separation of this coagulated matter. This novel method of separation is described as adapted to various other stages in the process of sugar manufacture.

Patent No. 3 (March, 1851) is of still more interest. It describes steam-heated open pans or boilers; vacuum concentration pans, jacketed and steam heated; methods of crystallization, and means for compressing the finished sugar into moulds. In February, 1852, he patented improvements on his original idea of plunger presses, together with several details of manufacture. In the following July came another patent filled with miscellaneous details, and again in November, are three patents

for "Improvements in apparatus for concentrating saccharine fluids." Finally in July, 1853, we have the last of the series which deals with improvements in the final stage of crystallization and refining.

I do not think that any of the patents could have repaid the inventor largely for the trouble and money he expended on them, nor do I know what accident turned his inventive mind in a direction divergent from the main road he followed by preference. Certain it is that he very quickly returned to metallurgical investigations, to follow them steadily to the end of his active commercial career. Perhaps it was natural that in most of his miscellaneous inventions—the manufacture of glass; the preparation of sugar; in his artillery; and later in his invention to prevent sea-sickness—Bessemer had little or no success, while on the other hand, in all those things which called forth the power of his artistic instinct, or the skill of the inventor to convert crude minerals to the use of man, his success was as certain as it was great. There must have been, nevertheless, a certain amount of commercial vitality in the Bessemer sugar patents, for I find that in 1856 a refinery on his system was in operation in Mill Street, Bermondsey, the property of the British Refining Company, which for a time were treating from fifty to seventy tons of sugar a week. It is also on record that he sold his French patents to a French syndicate.

In connection with the sugar machinery, it may be added that Bessemer acquired Baxter House, St. Pancras—later to become famous as the place where Bessemer steel was first made—for working an experimental plant. In the course of his experiments he imported large quantities of cane from the West Indies. These experiments were abandoned after the company was formed and the works established at Bermondsey, while a part, at all events, of the experimental plant was sent to the bronze powder factory, and converted for use there. Ultimately it was found that the British company could not stand against foreign competition, and it was wound up.

XIII.

The Crimean War, in which the allied armies of England and France were combined against those of Russia, showed clearly, among other failures, the lamentable inefficiency of heavy artil-

lery, which remained much in the same position which it occupied at the beginning of the century. It naturally followed that the War Office was besieged by crowds of inventors, each the possessor of the only secret for improving ordnance, while the records of the Patent Office bear evidence to the flood of invention turning in this direction. Gradually, improved systems came to the front, of which but few have survived; nevertheless the close of the struggle marked the birth of a new era in warfare. In these early times the names of Krupp and Armstrong, of Whitworth, of Palliser and others, are found among the list of inventors, and it is natural, therefore, that that of Bessemer should not be absent, although in the beginning his patents referred to artillery, and not to the use of steel, as was the case a little later. His first patent of this kind (August, 1853) was a very remarkable one, though I cannot find it ever went further than drawing paper. It was nothing less than a breechloading automatic gun, in which the force of recoil was used to set in motion self-acting apparatus, by the agency of water under pressure, or of steam, to perform the various functions of opening the breech, loading, closing the breech, firing and so on. There is of course nothing in common between the smoothbore cast-iron gun, discharging round shot, and the high velocity Maxim; still it is of great interest to bear in mind that the principle of automatic loading and firing was carefully described, and worked out in detail, more than forty years ago, by one of the most capable inventors of the century.

The next year (January, 1855) we find a patent for reducing recoil by making openings for gas escape near the muzzle, and the same specification claims making ordnance by casting them solid, and then boring. "The metal should be prepared according to the process described in the specification of Letter Patent, granted to Henry Bessemer, January 10, 1855," for "Improvements in the manufacture of Iron and Steel." Henceforth inventions with regard to artillery had a wider scope to Bessemer; he had found as he considered, a new material from which guns could be made stronger and more reliable than had been previously possible. It should be remarked with regard to this patent that Bessemer had been anticipated by Krupp, so far as casting solid and boring out were concerned, for Krupp had patented the same idea in December, 1852.

The next two patents (June and October, 1855) deal chiefly

with methods of casting with the new metal, but after this date the inventor is concerned wholly with details and new ideas. Then in January, 1861, we find a proposal for making a gun in two parts, and for casting steel projectiles which were afterwards stamped or rolled. The following April, he patented elongated projectiles with longitudinal grooves diverted at right angles, near the head of the shot; this was to ensure rotation. The specification is interesting in that it describes a method of strengthening old bronze guns by enlarging the bore, and inserting a lining tube, "of copper or gun metal, or wrought iron or steel." At a later date a fierce controversy raged between two rival re-inventors of this method. The specification of January, 1864, describes machinery for rolling spherical shot and has no great interest. In August, 1867, Bessemer patented an arrangement of breech-loading ordnance for firing heavy projectiles of from one to ten tons; the scheme is, however, of little interest, except that it contemplates the use of air compressed to from 5,000 to 10,000 pounds per square inch, as the propelling energy. In November, 1870, we have a very lengthy specification for a gun of great length in which the gas pressure is to be maintained uniform while the projectile is in the gun. This was to be effected by placing a steel block in the powder chamber, drilled with a large number of holes, perhaps one or two hundred, and each to contain a cartridge. Firing was to be automatic and successive. It is quite unnecessary to say that the invention was never tried; indeed one wonders to find it on our list. The idea of progressive explosions in a gun appears, however, to have possessed a special attraction to Bessemer at this time, for we find a second very elaborate specification on the same subject filed by him in June, 1871. The last patent we have, bears only incidentally on artillery; it is dated March, 1873, and has to do with steady-platforms for mounting guns at sea; this was suggested by his idea for suppressing sea-sickness, an idea which he pursued to its unfortunate end, with his characteristic energy.

XIV.

We come now to the commencement of the most important part of Henry Bessemer's career, for which his previous work had been a long preparation, and to which he was guided by

following up an investigation, of itself valueless, but which led the way towards the most important industrial discovery of the century—that of the "Bessemer process." As I have just mentioned, the inefficiency of the artillery employed by the English, French, and Russians during the Crimean War, encouraged a host of more or less practical inventors to devise new means of improving the durability and power of guns, and the range and penetration of projectiles. The end of round shot and cast iron or bronze heavy artillery was at hand, but the direction from which the improvement was to come had been scarcely indicated.

It was natural that Bessemer should be among the ranks of the artillery inventors. His first patent, as we have seen, dealt with a matter far ahead of the time; nothing less, indeed, than the automatic loading and firing of guns by the action of recoil. More practical were his further investigations. He had designed some elongated projectiles to be fired from a smooth bore, with the object of securing longer and greater penetration.

His ideas were ingenious and practical. He spirally grooved his elongated shot longitudinally, concluding that the reaction of the powder gases would cause rotation.

He laid his plans before the War Office, and received no consideration. Probably he did not seek for such, bearing in mind his past experience with government officials. But he went to Paris and offered his services to the Emperor Napoleon, who took a deep interest in the scheme. He gave Bessemer every possible facility. Firing trials were arranged at Vincennes, and thither the inventor went with a number of his projectiles—30-pounders. These were fired from a 4½-inch 12-pounder gun and fully proved the claims for rotation. But the guns were lamentably weak. On one of these occasions, Colonel Minié, the inventor of the rifle that bore his name, expressed his opinion to Mr. Bessemer that it was useless to fire such projectiles from a cast-iron gun. Stronger material was necessary. Mr. Bessemer realized the truth of this objection. How to obtain a stronger material was the problem awaiting solution. That was the beginning of the Bessemer process.

In following this investigation, the experiments of Fairbairn of melting scrap iron with pig probably suggested the line of experiments he at first decided to follow. Fairbairn, however, had melted his mixtures in a cupola furnace, with the result that

the iron was heavily charged with sulphur, and was, therefore, unsuited for his purpose.

To avoid this, Bessemer used a reverberatory furnace, the grate of which was wider than the hearth, while arrangements were made to introduce a plentiful supply of air at the back of the bridge, which, meeting with the gases from the furnace, caused a continuous and intense heat to sweep over the surface of the hearth, and thence it flowed to a down-cast shaft leading to the chimney. The hearth was filled with a bath of molten pig-iron into which were placed broken-up pieces of blister steel made from Swedish and other charcoal iron. The charge was melted in the bath without any contact with the fuel.

This arrangement formed the subject of the first of the long series of the Bessemer iron and steel patents. It is dated January 10, 1855, and is entitled, "The manufacture of iron and steel." Amongst a description of several other suggestions we have the following: "The combination by fusion of pig or cast iron with steel may be effected either in a reverberatory or cupola furnace. Thus steel may be used in a bath of molten cast iron in the reverberatory furnace. . . . The quantity of steel used with the iron will be regulated by the quality required in the mixture. After casting, it may be much softened by annealing." This was very interesting, but it was not the Bessemer process, only the first practical step toward it. The results obtained may be best described in Sir Henry Bessemer's own words: "Some of the samples of metal I produced by this process were, when annealed, of an extremely fine grain and great strength. At this stage of my experiments I determined on casting a small model gun, which in the lathe gave shavings slightly curled, and closely resembling the shaving from a steel ingot. The metal when polished also looked white and close-grained like steel. I was so well pleased with this casting that I took it over to Paris, obtaining an audience with, and showing it to, the Emperor, who had, in fact, encouraged me to make an attempt to improve the iron employed in making heavy ordnance. . . . His Majesty also gave me permission to erect my furnace at the government cannon foundry at Ruelle, near Angouleme, to which place I went with proper introductions, for the purpose of arranging all necessary details. I also sent over from England several thousand special firebricks for the erection of the furnace." But the furnaces at Ruelle were des-

tined never to be completed, for by an accident the investigator's attention was diverted to a different direction. I cannot do better than again quote Sir Henry's own description of the incident: "Some pieces of pig iron on one side of the bath attracted my attention by remaining unmelted in spite of the great heat of the furnace, and I turned a little more air through the fire bridge, with the intention of increasing the combustion; on again opening the furnace door, after an interval of half an hour, these two pieces of pig remained unfused. I then took an iron bar with the intention of pushing them into the bath, when I discovered they were merely thin shells of decarbonized iron, thus showing that atmospheric air alone was capable of wholly decarbonizing pig iron and converting it into malleable iron without puddling, or any other manipulations. It was this that gave a new direction to my thoughts, and after due consideration I became convinced that if air could be brought in contact with a sufficiently extensive surface of molten crude iron, the latter would rapidly be converted into malleable iron."

This accident was at once turned to account, and an interesting series of experiments carried out; but before we refer to these I may trace as briefly as possible the progress of the invention as shown in the Patent Office's records. I have already referred to the first; the second is dated 17th October, 1855, "The Manufacture of Cast Steel." In this a furnace was employed large enough to contain a series of crucibles, into each of which depended nearly to the bottom a pipe perforated with holes, but closed at the end. When the molten pig iron was charged with the crucibles, steam at first, and air under pressure afterwards, was forced through the pipes, with the molten metal escaping upwards. "Air is used to complete the operation; the change will soon became apparent; the metal, which may have lost much of its heat during the steaming process, will rapidly brighten up, an increase of flame will be observed, and a rapid increase in the temperature of the metal will take place." This is a very important point, because it shows how clearly Bessemer appreciated the end in view and the general way of attaining it, though his mechanical details were still crude and imperfect. He says: "The state of the metal may be tested by dipping out a sample, as practised in refining copper; if too much carbon is retained the pipe may again be introduced for a short time, or a small quantity of scrap iron may be put into it;

but if too much carbon has been driven off, an addition may be made of some melted iron from the finery or cupola furnace."

Next comes a specification dated December 7, 1855—"The manufacture of iron," in which the turning converter is first described. "The molten iron is to be refined after it leaves the blast furnace, and is still in a fluid state; for this purpose it is run into a preferably spherical or egg-shaped iron vessel lined with fire brick or other refractory material being a slow conductor of heat. The vessel is supported on a frame, and is fitted with a handle for tipping it to pour out its contents. By means of jointed or flexible or other pipes, a blast of air or steam or both is conveyed—below the surface of the molten metal, which it bubbles up, a highly heated blast of air being required. In either case the oxygen thus introduced into the metal will carry off a large portion of carbon and the impurities." The characteristics of blowing a charge are described in the specifications.

"During the operation the metal undergoes ebullition and increases in temperature; the appearance of the flame, sparks, and slag issuing from the top of the crucible indicate the state of the metal. After the operation has continued for about half an hour the flame gradually diminishes, and thus indicates to the workman that the process is completed, and that the crude metal has been converted into a nearly pure malleable iron." The patents dated January 4 and February 12, 1856, deal with improved and new mechanical details of the process, and on the following March 15th we find an interesting development of the suggestion for recarburizing referred to in the specification of October 7, 1855. "Carbonaceous matters, such as charcoal, anthracite, or carbonate of iron, rich in carbon, may be placed in the crucible or vessel with the metal—or gases produced by passing air or steam through ignited fuel, may be forced into the molten metal. The gases thus used may have either a carburizing or decarburizing effect, whereby the inventor can produce either malleable iron or steel as described."

Now we will turn from the Patent Office record to the new series of experiments conducted by Mr. Bessemer at Baxter House, St. Pancras. After the incident which led him to abandon the reverberatory furnace, the period extends from about the middle of 1855 to the middle of 1856, when he prepared his famous paper for the British Association for the Advancement of

Science. Accident had shown him that air alone would decarburize pig iron; this, therefore, was the line he decided to follow. He carried out a series of experiments with crucibles containing melted pig iron, and exposed it to the action of a blast of air admitted near the bottom of the charge, as described in his specification of October 17, 1855, above referred to. The crucibles were half filled, the charge in each being about ten pounds of metal, and this, after half an hour's blowing, was converted into soft malleable iron. So far so good; the complete decarburizing action was proved, but the crucible had to be kept at a high temperature in a furnace.

XV.

The problem now was to decarburize the charge completely, and to keep it in a fluid condition by the vehement combustion of impurities maintained by a sufficient blast of air forced into the molten mass under considerable pressure. The converter was a fixed cylindrical fire-clay lined chamber, with a row of tuyeres round it near the bottom, and a hole at the top for the escape of gases. The charge was ten hundredweight, and the pressure of the blast about fifteen pounds. After the blast had been turned on for about ten minutes all remained quiet; then issued such an eruption of sparks and flames, such a succession of explosions and discharges of molten slags, that all the spectators were desperately alarmed, and the building was nearly set on fire. After a time the volcanic action ceased, and on emptying the converter the charge was found to be changed into "wholly decarburized malleable iron." In this way the Bessemer process came into existence; all that remained was patient investigation and modification of mechanical details; and the far more difficult task of overcoming prejudice, disbelief, and hostility. Many years had to pass before these latter difficulties were subdued.

In February, 1856, the converting vessel on trunnions was patented, naturally in a somewhat crude form, though the experiments at Baxter House were carried on in fixed converters; at all events this was so as late as August, 1856, when his British Association paper was written. But during the whole of that year he had not ceased to improve the details of the process, more especially giving his attention to the production of

steel in the converter. In this connection the patent of May 31st is of interest; it was by this patent he was the first to claim casting under hydraulic pressure, a claim under which Sir Joseph Whitworth paid royalty some years afterwards.

As may be readily supposed these experiments had not taken place in silence. Bessemer was at that time an eminently successful man whose position in practical science was assured. The new process, so revolutionary in its method, so unlimited in its application and development—if half were true that was said about it—created a profound sensation in certain small circles, and the announcement that he would read on August 13, 1856, a paper on his process, before the British Association for the Advancement of Science, which that year met in Cheltenham, was received with the deepest interest, heightened by the somewhat sensational title, "On the Manufacture of Malleable Iron and Steel without Fuel." I have no hesitation in reproducing this paper here; it possesses deep interest, and is a somewhat rare document, the members of Council of the British Association having sagaciously decided subsequently that it was not worthy to find a place in their *Transactions*.

Mr. Bessemer has placed on record how the writing and reading of this paper came about: "I consulted Mr. George Rennie, the eminent civil engineer. I showed him a small upright fixed cylindrical converter, and in it we made a charge of seven hundred weight of Blaenavon pig iron into an ingot of malleable iron. Mr. Rennie was in raptures with the result, and said, 'You must not keep the light under a bushel for a single day longer; and, by the bye, there is a first-rate opportunity for you. The British Association meets at Cheltenham next Tuesday; read a paper there, by all means. I am president of the mechanical section; it is true all the papers are arranged, but if you will write a paper I will take the responsibility of placing it first on the list.' He kept his promise, and I read my paper on the 'Manufacture of Malleable Iron without Fuel,' which appeared *verbatim* in the next day's *Times*."

The following is the text of the paper:

"The manufacture of iron in this country has attained such an important position that any improvement in this branch of our national industry cannot fail to be a source of general interest and will, I trust, be sufficient excuse for the present brief and, I fear, imperfect paper. I may mention that for the last two years my attention has been almost exclusively directed to the manufacture of malle-

able iron and steel in which, however, I had made but little progress until within the last eight or nine months. The constant pulling down and rebuilding of furnaces and the toil of daily experiments with large charges of iron had already begun to exhaust my stock of patience, but the numerous observations I had made during this very unpromising period all tended to confirm an entirely new view of the subject which at that time forced itself upon my attention, viz., that I could produce a much more intense heat without any furnace or fuel than could be obtained by either of the modifications I had used; and, consequently, that I should not only avoid the injurious action of mineral fuel on the iron under operation, but I should, at the same time, avoid also the expense of fuel. Some preliminary trials were made on from 10 pounds to 20 pounds of iron, and, although the process was fraught with considerable difficulty, it exhibited such unmistakable signs of success as to induce me at once to put up an apparatus capable of converting about 7 hundredweight of crude pig iron into malleable iron in 30 minutes. With such masses of metal to operate on, the difficulties which beset the small laboratory experiments of 10 pounds entirely disappeared. On this new field of inquiry I set out with the assumption that crude iron contains about five per cent. of carbon; that carbon cannot exist at a white heat in the presence of oxygen without uniting therewith and producing combustion; that such combustion would proceed with a rapidity dependent on the amount of surface of carbon exposed; and, lastly, that the temperature which the metal would acquire would be also dependent on the rapidity with which the oxygen and carbon were made to combine, and consequently that it was only necessary to bring together the oxygen and carbon in such a manner that a vast surface should be exposed to their mutual action in order to produce a temperature hitherto unattainable in our largest furnaces. With a view of testing practically this theory I constructed a cylindrical vessel 3 feet in diameter, and 5 feet in height, somewhat like an ordinary cupola furnace, the interior of which is lined with firebricks, and at about 2 inches from the bottom of it I insert five tuyere pipes, the nozzles of which are formed of well-burned fire-clay, the orifice of each tuyere being about ⅜ of an inch in diameter; they are so put into the brick lining (from the outer side) as to admit of their removal and renewal in a few minutes when they are worn out. At one side of the vessel, about half way up from the bottom, there is a hole made for running in the crude metal, and on the opposite side there is a tap-hole stopped with loam, by means of which the iron is run out at the end of the process. In practice this converting vessel may be made of any convenient size, but I prefer that it should not hold less than one, or more than five, tons of fluid iron at each charge. The vessel should be placed so near to the discharge hole of the blast furnace as to allow the iron to flow along a gutter into it; a small blast cylinder will be required capable of compressing air to about 8 or 10 pounds to the square inch. A communication having been made between it and the tuyeres before named, the converting vessel will be in a condition to commence work; it will, however, on the occasion of its being used after relining with firebricks, be necessary to make a fire in the interior with a few buckets of coke, so as to dry the brick-work and heat up the vessel for the first operation, after which the fire is to be all carefully raked out at the tapping hole which is again to be made good with loam. The vessel will then be in readiness to commence work, and may be so continued without any use of fuel until the brick lining in the course of time becomes worn away and a new lining is required. I have before mentioned that the tuyeres are situated close to the bottom of the vessel; the fluid metal will

therefore rise some eighteen inches or two feet above them. It is therefore necessary, in order to prevent the metal from entering the tuyere holes, to turn on the blast before allowing the fluid crude iron to run into the vessel from the blast furnace. This having been done, and the fluid iron run in, a rapid boiling up of the metal will be heard going on within the vessel, the metal being tossed violently about and dashed from side to side, shaking the vessel by the force with which it moves from the throat of the converting vessel. Flame will then immediately issue accompanied by a few bright sparks. This state of things will continue for about fifteen or twenty minutes, during which time the oxygen in the atmospheric air combines with the carbon contained in the iron, producing carbonic acid gas and at the same time evolving a powerful heat. Now, as this heat is generated in the interior of, and is diffused in innumerable fiery bubbles throughout the whole fluid mass, the metal absorbs the greater part of it, and its temperature becomes immensely increased, and by the expiration of the fifteen or twenty minutes before named that part of the carbon which appears mechanically mixed and diffused through the crude iron has been entirely consumed. The temperature, however, is so high that the chemically combined carbon now begins to separate from the metal, as is at once indicated by an immense increase in the volume of flame rushing out of the throat of the vessel. The metal in the vessel now rises several inches above its natural level and a light frothy slag makes its appearance, and is thrown out in large foam-like masses. This violent eruption of cinder generally lasts about five or six minutes, when all further appearance of it ceases, a steady and powerful flame replacing the shower of sparks and cinder which always accompanies the boil. The rapid union of carbon and oxygen which thus takes place adds still further to the temperature of the metal, while the diminished amount of carbon present allows a part of the oxygen to combine with the iron, which undergoes combustion and is converted into an oxide. At the excessive temperature that the metal has now acquired the oxide, as soon as formed, undergoes fusion, and forms a powerful solvent of those earthy bases that are associated with the iron. The violent ebullition which is going on mixes most intimately the scoria and the metal, every part of which is thus brought into contact with the fluid oxide which will thus wash and cleanse the metal most thoroughly from the silica and other earthy bases which are combined with the crude iron, while the sulphur and other volatile matters which cling so tenaciously to iron at ordinary temperature are driven off, the sulphur combining with the oxygen and forming sulphurous acid gas. The loss of weight of crude iron during its conversion into an ingot of malleable iron was found on a mean of four experiments to be 12½ per cent., to which will have to be added the loss of metal in finishing rolls. This will make the entire loss probably not less than 18 per cent. instead of above 28 per cent., which is the loss on the present system. A large portion of this metal is, however, recoverable by treating with carbonaceous gases the rich oxides thrown out of the furnace by the boil. These slags are found to contain innumerable small grains of metallic iron which are mechanically held in suspension in the slags and may be easily recovered. I have before mentioned that after the boil has taken place a steady and powerful flame succeeds, which continues without any change for about ten minutes, when it rapidly falls off. As soon as this diminution of flame is apparent the workman will know that the process is completed, and that the crude iron has been converted into pure malleable iron, which he will form into ingots of any suitable size and shape by simply opening the tap-hole of the converting vessel and allowing the fluid malleable iron to flow into ingot moulds placed there to receive it.

The masses of iron thus formed will be perfectly free from any admixture of cinder, oxide, or other extraneous matters, and will be far more pure, in a more forward state of manufacture than a pile formed of ordinary puddle bars. And thus it will be seen that by a single process requiring no manipulation or particular skill and with only one workman, from three to five tons of crude iron pass into the condition of several piles of malleable iron in from thirty to thirty-five minutes, with the expenditure of about one-third part the blast now used in a finery furnace with an equal charge of iron, and with the consumption of no other fuel than is contained in the crude iron. To those who are best acquainted with the nature of fluid iron it may be a matter of surprise that a blast of cold air forced into melted crude iron is capable of raising its temperature to such a degree as to retain it in a perfect state of fluidity after it has lost all its carbon and is in the condition of malleable iron, which in the highest heat of our forges only becomes softened into a pasty mass. But such is the excessive temperature that I am enabled to arrive at with a properly shaped converting vessel and a judicious distribution of the blast, that I am enabled not only to retain the fluidity of the metal, but to create so much surplus heat as to remelt the crop ends, ingot runners, and other scrap that is made throughout the process, and thus bring them without labor or fuel into ingots of a quality equal to the rest of the charge of new metal. For this purpose a small arched chamber is formed immediately over the throat of the converting vessel, somewhat like the tunnel head of the blast furnace. This chamber has two or more openings on the side of it, and its floor is made to slope downwards to the throat. As soon as a charge of fluid malleable iron has been drawn off from the converting vessel the workman will take the scrap intended to be worked into the next charge and proceed to introduce the several pieces into the small chamber, piling them up around the opening of the throat. When this is done he will run in his charge of crude metal and again commence the process. By the time the boil commences the bar ends and other scrap will have acquired a white heat, and by the time it is over most of them will have been melted and run down into the charge. Any pieces, however, that remain may then be pushed in by the workman, and by the time the process is completed they will all be melted and ultimately combined with the rest of the charge, so that all the scrap iron, whether cast or malleable, may thus be used up without any loss or expense. As an example of the power that iron has of generating heat in this process I may mention a circumstance that occurred to me during my experiments.

"I was trying how small a set of tuyeres could be used; but the size chosen proved to be too small, and after blowing into the metal for one hour and three quarters, I could not get up heat enough with them to bring on the boil. The experiment was, therefore, discontinued, during which time two-thirds of the metal solidified, and the rest was run off. A larger set of tuyere-pipes were then put in, and a fresh charge of fluid iron run into the vessel, which had the effect of entirely remelting the former charge, and when the whole was tapped out it exhibited, as usual, that intense and dazzling brightness peculiar to the electric light.

"To persons conversant with the manufacture of iron it will be at once apparent that the ingots of malleable metal which I have described will have no hard or steely parts, such as is found in puddled iron, requiring a great amount of rolling to blend them with the general mass, nor will such ingots require an excess of rolling to expel cinder from the interior of the mass, since none can exist in the ingot, which is pure and perfectly homogeneous throughout, and hence requires only as

much rolling as is necessary for the development of fibre; it therefore follows that instead of forming a merchant bar or rail by the union of a number of separate pieces welded together, it will be far more simple and less expensive to make several bars or rails from a single ingot; doubtless this would have been done long ago had not the whole process been limited by the size of the ball which the puddler could make.

"The facility which the new process affords of making large masses will enable the manufacturer to produce bars that on the old mode of working it was impossible to obtain; while, at the same time, it admits of the use of some powerful machinery whereby a great deal of labor will be saved, and the process be greatly expedited. I merely mention this fact in passing, as it is not my intention at the present moment to enter upon any details of the improvements I have made in this department of the manufacture, because the patents which I have obtained for them are not yet specified. Before, however, dismissing this branch of the subject, I wish to call the attention of the meeting to some of the peculiarities which distinguish cast steel from all other forms of iron, namely, the perfect homogeneous character of the metal, the entire absence of sand-cracks or flaws, and its greater cohesive force and elasticity as compared with the blister steel from which it is made, qualities which it derives solely from its fusion and formation into ingots, all of which properties malleable iron acquires in like manner by its fusion and formation into ingots in the new process. Nor must it be forgotten that no amount of rolling will give to blister steel (although formed of rolled bars) the same homogeneous character that cast steel acquires by a mere extension of the ingot to some ten or twelve times its original length.

"One of the most important facts connected with the new system of manufacturing malleable iron, is that all iron so produced will be of that quality known as charcoal iron, not that any charcoal is used in its manufacture, but because the whole of the processes following the smelting of it are conducted entirely without contact with or the use of any mineral fuel; the iron resulting therefrom will, in consequence, be perfectly free from those injurious properties which that description of fuel never fails to impart to iron that is brought under its influence. At the same time, this system of manufacturing malleable iron offers extraordinary facility for making large shafts, cranks, and other heavy masses; it will be obvious that any weight of metal that can be found in ordinary cast iron by the means at present at our disposal may also be found in molten malleable iron, and be wrought into the forms and shapes required, provided that we increase the size and power of the machinery to the extent necessary to deal with such large masses of metal. A few minutes' reflection will show the great anomaly presented by the scale on which the consecutive processes of iron making are at present carried on. The little furnaces originally used for smelting have assumed colossal proportions, and are made to operate on 200 or 300 tons of material at a time, giving out 10 tons of fluid metal at a single run. The manufacturer has thus gone on increasing the size of his smelting furnaces and adapting to their use the blast apparatus of the requisite proportions, and has by this means lessened the cost of production in every way; his large furnaces require a great deal less labor to produce a given weight of iron than would have been required to produce it with a dozen furnaces, and in like manner his cost of fuel, blast, and repairs, while he ensures a uniformity in the result that never could have been arrived at by the use of a multiplicity of small furnaces. While the manufacturer has shown himself fully alive to these advantages, he has still been under the necessity of leaving the succeeding operations to be carried out on a scale

wholly at variance with the principles he has found so advantageous in the smelting department. It is true that hitherto no better method was known than the puddling process, in which from 400 weight to 500 weight of iron is all that can be operated upon at a time, and even this small quantity is divided into homeopathic doses of some 70 pounds or 80 pounds, each of which is moulded and fashioned by human labor, carefully watched and tended in the furnaces, and removed therefrom one at a time to be carefully manipulated and squeezed into form. When we consider the vast extent of the manufacture, and the gigantic scale on which the early stages of the process is conducted, it is astonishing that no effort should have been made to raise the after processes somewhat nearer to a level commensurate with the preceding ones, and thus rescue the trade from the trammels which have so long surrounded it.

"Before concluding these remarks, I beg to call attention to an important fact connected with the new process, which affords peculiar facilities for the manufacture of cast steel. At that stage of the process immediately following the boil, the whole of the crude iron has passed into the condition of cast steel of ordinary quality; by the continuation of the process the steel so produced gradually loses its small remaining portion of carbon, and passes successively from hard to soft steel, and from soft steel to steely iron, and eventually to very soft iron; hence at a certain period of the process any quality of metal may be obtained; there is one in particular, which by way of distinction I call semi-steel, being in hardness about midway between ordinary cast steel and soft malleable iron. This metal possesses the advantage of much greater tensile strength than soft iron; it is also more elastic, and does not readily take a permanent set, while it is much harder, and is not worn or indented so easily as soft iron; at the same time it is not so brittle or hard to work as ordinary cast steel. These qualities render it eminently well adapted to purposes where lightness and strength are specially required, or where there is much wear, as in the case of railway bars, which, from their softness and lamellar texture, soon become destroyed. The cost of semi-steel will be a fraction less than iron, because the loss of metal that takes place by oxidation in the converting vessel is about 2½ per cent. less than it is with iron; but, as it is a little more difficult to roll, its cost per ton may fairly be considered to be the same as iron. But as its tensile strength is some 30 or 40 per cent. greater than bar iron, it follows that for most purposes a much less weight of metal may be used, so that taken in that way the semi-steel will form a much cheaper metal than any with which we are at present acquainted.

"In conclusion, allow me to observe that the facts which I have had the honor to bring before the meeting have not been enlisted from mere laboratory experiments, but have been the result of working on a scale nearly twice as great as is pursued in our largest iron works, the experimental apparatus doing 7 cwt. in 30 minutes, while the ordinary puddling furnace makes only 4½ cwt. in two hours, which is made into six separate balls, while the ingots, or blooms, are smooth, even prisms 10 inches square by 30 inches in length, weighing about equal to ten ordinary puddle balls."

XVI.

In spite of the brief notice, the somewhat sensational title of this paper had attracted much attention, and not a few persons whose names then stood deservedly high as manufacturers of

iron were present chiefly to ridicule the author of such an absurd proposition. Contrary, however, to all expectations, the paper was enthusiastically received, and one ironmaster, who in the first instance had shown much incredulity, offered to place his works at Mr. Bessemer's disposal for any experiments he desired to make. Mr. James Nasmyth, who was present, with appreciative enthusiasm, held up at arm's length one of Mr. Bessemer's samples, exclaiming: "Here is a true British nugget!" This bar of iron was rolled, piled, and re-rolled at Woolwich Arsenal, and fully proved the soundness of the principle on which the invention was based.

The historic paper in a few days became a theme for the whole newspaper press of the country. Many ironmasters rushed up to London in hot haste to see Mr. Bessemer, fearing that the new process might be monopolized; one large firm (only three days after the reading of the paper) made a formal offer of £50,000 for the English patent, which was, however declined. The impression produced on the minds of practical ironmasters by the announcement of the invention, may be imagined, when we state that within one month from the appearance of Mr. Bessemer's paper in the *Times*, no less than £27,000 had been received for licenses to use the invention in Great Britain alone. All this excitement and premature action had naturally very unfortunate results. At the time Bessemer had only a very limited knowledge of the capacity of his invention, which was of course in an experimental stage; and still less did the enterprising ironmasters know what ores were suitable for treatment. Trials of the process were hastily made at several works throughout the country, all ending in failure for want of care and knowledge. Mr. Bessemer and his process were condemned as loudly and unreasonably as he had been praised, and once more the press was busy, but this time in showing that the invention for which such great results had been claimed, was nothing more than the dream of a wild enthusiast; one journal described the process as "a brilliant meteor that had flitted across the metallurgical horizon, dazzling all beholders for a moment, only to die out and leave no trace behind."

Scientists invented theories to show how it never could have succeeded, and practical iron and steel makers joined in condemning the folly, as they deemed it, of those few of their num-

ber who had been weak enough to believe in its practicability. Experience, they said, had clearly shown that the most powerful furnaces then known, with the most lavish expenditure of fuel, applied for any amount of time, were insufficient to fuse pure malleable iron on a commercial scale; yet Mr. Bessemer proposed to arrive at this unattainable temperature in masses of five tons, in the short space of twenty minutes wholly without the use of fuel, except such as was supplied by the impurities of the crude iron itself. How, it was asked, could any practical man have been so foolish as for one moment to have entertained such a proposal?

So unanimous was the condemnation and abuse, at this period, that the Council of the British Association, as I have already said, came to the conclusion that so great a fallacy ought not to be encouraged by its publication in their *Transactions*, and notwithstanding the loud acclamations with which the paper had been received when it was read, and in spite of the proofs afforded of its correctness in principle by the exhibition at the meeting of rolled bars made by the process, that body supported the universal condemnation, by omitting all mention of the paper in their published *Transactions*.

I would have liked to add here the names of those leaders of science, who thus distinguished themselves. They ought to be placed on record.

With this universal condemnation of the process, what did Mr. Bessemer do? He had more than recouped himself for his first outlay and loss of time by the receipt of £27,000 which had been voluntarily offered him for licenses by persons who had sought him out, and were willing to back their own opinion of its merits, and who would, under the terms arranged, reap an immense return in case the process turned out successful when tried on a commercial scale. He might, therefore, have retired from the field, accepting the verdict passed on his invention; but he knew that the various reasons assigned for its failure by practical ironmakers were wholly fallacious, and that the defects which had presented themselves did not touch the principle on which the invention was based. Instead, therefore, of wasting time in arguing the question with a multitude of antagonists, as a weaker man would have done, he addressed himself to overcome the difficulties of detail. The task was a great one, and month after month rolled on; furnaces, machinery, and

apparatus were constructed at the Baxter House works, to be pulled down and rebuilt or altered; thousands of pounds were spent in experiments, and some two years passed away in this incessant preliminary work. But Mr. Bessemer never lost heart, or yielded to the solicitation of his friends, who again and again urged him to give up; this he would not do, as he knew he was getting nearer to the end of his labors; the rapid wear of vessels from excessive heat had been remedied; the necessity of tapping the vessel had been evaded by mounting it on trunnions; the distribution of the metal into a number of moulds, while still fluid, had been perfected; during the third year—1858—success was achieved, and steel of excellent quality was made at Baxter House from molten pig iron in fifteen minutes, without the employment of skilled labor, without manipulation of any kind, and without the employment of fuel. At last the correctness of the views enunciated in the paper read at Cheltenham was clearly demonstrated, and all the theories set up both by scientists and practical men to show the impossibility of the process were utterly demolished.

But after this was done, a new and powerful opposition was set up in the steel trade. Those who had disbelieved were convinced and alarmed; a combination was formed to generally disparage and talk down the process, and so effectually, that every effort to induce steelmakers of Sheffield to give it a trial was unsuccessful. Circumstances, however, were now wholly changed, and Mr. Bessemer, with assured success laboriously achieved, was in no mood to yield to this nature of obstruction. He determined, therefore, in 1858, to erect steel works in Sheffield itself, in the heart of the enemy's country, and thus openly oppose and undersell the steelmaker in his own market. By this bold stroke of policy he finally succeeded in introducing the process that has effected an entire revolution in some of the greatest branches of the iron trade of the world.

XVII.

During the whole of this trying period, in the face of ridicule and of opposition, with discouragement intensified by the recollection of the brief triumph obtained at Cheltenham, and in the presence of constant financial straits, Bessemer never despaired. He knew that he was right and that the time would come when

those loudest in their abuse would be put to shame. Carrying the war into the enemies' camp at Sheffield was a stroke of genius. He could not start large works; his means would not permit that. In fact, the total capital available was less than £12,000. Messrs. Bessemer & Longsdon subscribed about £6,000; Messrs. W. & G. Galloway, £5,000, and Mr. W. D. Allen, £500. These were narrow means with which to enter on so great a struggle, but as we shall see, they sufficed.

I have explained how the boyish intimacy between Bessemer and the Allens had strengthened as time went on; how it had been cemented by marriage, and how one of the Allen brothers —Richard—controlled the bronze powder secret business. A younger brother, William D. Allen, had left school when he was fourteen, and Bessemer eleven years older. Shrewd and energetic, W. D. Allen became (as I have said) young Bessemer's confidential assistant in the many interests he was then pushing in his embossing trade; the type-founding; the sugar machinery; to some small extent in the bronze powder business; and in his earliest experiments at Baxter House. From that time to the end of his life, two years ago, W. D. Allen was identified with the Bessemer process. Throughout the period of struggle, and later through all the long time of success and prosperity, he and Bessemer stood side by side. I shall have more to say about Mr. Allen when I come to speak of the part taken by Alexander Holley in the development of the Bessemer process.

XVIII.

The eighteen months that followed the reading of the famous paper at Cheltenham were probably the hardest months of Bessemer's long life.

The paper which he read before the Institution of Civil Engineers on the 24th of May, 1859, shows us clearly how far he had progressed since his first experiments in the fixed vertical converter. It is entitled the "Manufacture of Malleable Iron and Steel," and I take from it the following extracts:

"It need not, therefore, be a matter of surprise that when it was first proposed by the author to convert crude pig iron into malleable iron while in a fluid state, and to retain the fluidity of the metal for a sufficient time to admit of its being cast into moulds without the employment of any fuel in the process, that this proposition was almost generally looked upon as a chimera, or as the mere day-

dream of an enthusiast, which the quiet everyday practical man felt bound to disbelieve, although the laws on which the whole theory of the invention was based were well known, hence the process was recognized from the very first by many of the scientific men of the day. The theory which was advanced in the original paper, read at the British Association at Cheltenham in August, 1856, and the experiments subsequently shown in London, sufficed to demonstrate three most important and incontrovertible facts: first, that crude pig iron could be wholly decarburized while still retaining the fluid state; secondly, that by the injection of atmospheric air into the fluid metal the combustion thereby produced would, in the absence of fuel, raise the temperature of the metal to a degree never before attained in metallurgical operations; and thirdly, that the iron so decarburized without the employment of fuel would retain its fluidity long enough to enable it to be cast into ingots capable of extension under the hammer or the rolls. Nothing that has since been discovered has altered, or even modified these facts. The same apparatus as that shown in London nearly three years ago will, with the proper quality of pig iron and the practical knowledge since acquired, produce both malleable iron and steel equal to any of the samples now exhibited. It is singular to observe how prone the practical man is to deny to the inventor of a new process that very practical knowledge which he himself so much values. If the inventor cannot show in the first week of his apprenticeship the skill which is well known can only be acquired by years of practice, it suffices to condemn the new system which, in its mere infancy, is expected to be as perfect in all its details as that which the manufacturers have grown gray in the daily practice of. The same deep conviction of the truth on which the new process is based, and which led the author to bring it before the British Association, has since determined him (in spite of the opinions loudly expressed against the process) to pursue one undeviating course until the present time, and to remain silent for years under the scepticism of those who predicted its failure, rather than again to bring forward the invention until he had himself practically and commercially worked the process, and produced by it both iron and steel of a quality which could not be surpassed by any specimens of those metals made by the tedious and expensive processes now in general use. The want of success which attended some of the early experiments was accounted for by practical ironmakers in various ways. The majority contended that the metal was burned, or destroyed by the excessive temperature it acquired in the process; others declared that the metal was too dry, and that it could never become tough or fibrous, except by a plentiful admixture of cinder; while a third section traced every fault to the crystalline condition of cast metal, which they said could never become tough or capable of bending safely after having once been in a fluid state. Either of these supposed causes of failure would, if well founded, have sufficed to utterly destroy the whole value of the process. Objections of so grave a character, vehemently urged by practical ironmakers, were sufficient to damp the energy of the inventor, who saw that his only hope of success lay in the proof that these practical men were wholly in the wrong. Mature reflection convinced him that the objections so advanced were groundless, and that the reasons assigned had nothing whatever to do with the failure in those cases where failure had ensued. The practical man had learned from long experience that when masses of tough fibrous iron were kept for a long period of time at a high temperature the metal would gradually assume a crystalline texture and become what is termed burnt iron. Applying this isolated fact, therefore, to the new process, he arrived at once at the conclusion that the high temperature of the

iron during the Bessemer process produced the same result, without taking into consideration the fact that the metal in the Bessemer process was a fluid, and in that condition it was wholly unaffected by any law of crystallization, and that the pouring of such metal into a cold cast-iron mould and its consequent solidification in one or two minutes afforded no time for the formation of large and well defined crystals, which can only result from a slow aggregation of atoms, as in large forgings, where the time allowed for the development of the crystal varies, say from one hundred to five hundred hours, whereby the planes of cleavage of the mass are so perfectly marked as to form lines of separation and consequently of weakness in the metal.

"As to the second objection—the impossibility of producing a tough, strong, or fibrous iron, without an admixture of cinder—this is a similar error. It will be readily understood that puddled iron may easily become too dry, that is, the separate granules may become coated with a dry hard scale, such as is produced by heating an iron bar to redness. Pieces of iron, so oxidized, would not adhere together. But if a little sand be thrown on to a surface so oxidized, a fluid silicate of iron or "cinder" will be formed. If pressure be then applied to two or more surfaces of highly heated iron, with this fluid, the latter will be displaced, and the metallic surfaces, coming into actual contact, a union will be effected. It will be obvious, however, that these facts in no way apply to metal formed into a mass while fluid, there being no oxidized surface to prevent the uniform and perfect cohesion of every particle of the whole mass.

"The third objection that iron, once rendered fluid, could never become tough and capable of bending, is wholly disproved by the samples produced, which sufficiently show the enormous amount of strain which iron rendered crystalline by fusion only, is capable of sustaining before rupture. It must be borne in mind, that the fracture of rolled metal does not necessarily show this so-called fibrous condition, for if a perfect and equal amount of cohesion exists among all the particles of the mass, the fracture will follow the line of force, and the bar will break in nearly a straight line through the smallest part. The long-jagged irregular fracture, which takes place on breaking puddled iron, is only an additional proof of its weakness and want of uniformity of texture, produced chiefly by the diffusion of cinder throughout the mass, giving to it a flaky or laminated texture, lessening its cohesion.

"Chemical investigation soon pointed out the real source of difficulty. It was found that, although the metal could be wholly decarburized and the silicon be removed, the quantity of sulphur and phosphorus was but little affected. As different samples were carefully analyzed, it was ascertained that the red shortness was always produced by sulphur, when present to the extent of one-tenth per cent., and that cold shortness resulted from the presence of a like quantity of phosphorus. It therefore became necessary to remove these substances. Steam and pure hydrogen gas were tried, with more or less success, in the removal of sulphur, and various fluxes, composed chiefly of silicates of the oxides of iron and manganese, were brought in contact with the fluid metal, during the process, and the quantity of phosphorus was thereby reduced. Many months were thus consumed in laborious and expensive experiments, a few steps in advance were gained and many valuable facts were elicited. New patents and new apparatus followed in due course, when it was happily suggested that if it were possible to obtain some comparatively pure pig iron free, or nearly so, from sulphur or phosphorus, a proof would at once be given of the correctness of the views entertained with reference to these substances. Such a specimen of iron having

been procured, it was found that the steel of a fair average quality could be readily made from it. Indian and Nova Scotia iron were next tried, and no doubt was then entertained of the value and ultimate success of the process. The results thus obtained caused a total change in the direction in which the efforts of Messrs. Bessemer and Longsdon were directed. It was determined by them at once to import some of the best pig iron from Sweden, from which iron and steel of excellent quality were made, and the produce was used for almost every purpose for which the highest qualities of steel are employed. It was then decided to discontinue for a time all further experiments, and to erect steel works at Sheffield, for the express purpose of fully developing and working the new process commercially, and thus correcting and setting at rest the erroneous impressions that were generally entertained with reference to the invention.

"At a time when the manufacture of ordnance occupied so large a share of public attention, it may be interesting briefly to point out the great facility which the Bessemer process affords, of forming masses both of malleable iron and steel, of a size suitable for the heaviest ordnance, without any welding together of separate slabs, or the more costly mode of building up the gun with pieces, accurately turned and fitted together. Many attempts have been made to produce wrought iron ordnance, and this object has been successfully accomplished, in the case of the large gun produced at the Mersey forge. But however perfect this one gun may be, the time required to make it, and its immense cost, manifestly leave it still a desideratum to produce guns rapidly and cheaply, of a material equal to, or greater in tensile strength, than wrought iron, and, if possible, free from the liability to flaws which that material has, and to deterioration during its long exposure to a welding heat. It is believed that the Bessemer process supplied this desideratum, for masses of cast metal can be produced of 10 or 20 tons in weight in a single piece, and two or three such pieces may be conveniently made, by the same apparatus in one day. The metal, so made, may be either soft malleable iron, or soft steel. Ordnance may also be cast, of malleable iron, with a steel lining or core, or the steel lining may be afterwards fitted to it, so as, in either case, to obtain in the compound mass, the hardness and power of one material to resist abrasion, and the tenacity inherent in the other material. In order to show the extreme toughness of such iron, and to what a strain it may be subjected, without bursting, several cast and hammered cylinders were placed cold under the steam-hammer, and were crushed down, without the least appearance of tearing of the metal. Now these cylinders were drawn down from a round cast-iron ingot, only 2 inches larger in diameter than the finished cylinder, and in the precise manner in which a gun would be treated. They may, therefore, be considered as short sections of an ordinary 9-pounder field-gun.

"Iron so made requires very little forging, indeed the mere closing of the pores of the metal seems all that is necessary. The tensile strength of the samples, as tested at the Royal Arsenal, was 64,566 pounds per square inch, while the tensile strength of pieces cut from the Mersey gun gave a mean of 50,624 pounds longitudinally and 53,339 pounds across the grain, thus showing a mean of 17,550 pounds per square inch in favor of the Bessemer iron."

This paper was not very well received at the Institution of Civil Engineers, and was attacked by several eminent opponents, who doubted the results claimed, and saw little or no prospect

of success for the process. These hostile critics failed utterly to grasp the great facts of which Bessemer himself did not realize the full value, for they knew but little of the character of the man who had erased the word "impossible" from his dictionary. Colonel Eardly Wilmot, R.A., was a marked exception to most of those who took part in the discussions, either condemning, or "damning with faint praise."

XIX.

Although the Sheffield works of Bessemer & Co. were started in 1858, the samples shown to illustrate the Institution paper, read in May, 1859, were not of the material the world knows now as "Bessemer steel." This is proved by a brief entry by Mr. W. D. Allen in an old diary for 1859, under the date of Saturday, June 18: "First made Steel Direct." The company had made steel before, and had placed it on the market, but as shown by this entry it could not have been made "direct."

Curiously enough, it was during this same month of June, 1859, that Bessemer tool steel became a recognized article of manufacture, as is shown by the following extract from the *Mining Journal* of June 4, 1859; it will be noticed that there is an obvious error in the prices given:

> "In this day's *Journal* we quote, for the first time, amongst the metallic manufactures of this country, the steel produced by the process patented by Mr. Bessemer, and we are informed that the new material can be supplied in almost any quantities. The usual price of engineers' tool steel is from £2 15s. to £3 5s. per cwt., while Mr. Bessemer offers an article, which prominent judges pronounce equal to the best, at £2 4s., his other kinds of steel being proportionately lower. As to the quality of the article there can be little doubt, since the tests to which it has been submitted at Woolwich gave much satisfaction to the officials, and we understand a contract for a considerable period has been concluded with Mr. Bessemer. With a steel of equal quality a little more than two-thirds the usual price, it would appear almost impossible for success to be wanting to the seller, while the pecuniary advantage to the consumer will be at once verified, so that it is needless to commend Bessemer's steel to the consideration of our readers."

The tool steel referred to, and, indeed, all the steel made in the Sheffield works prior to the 18th June, 1859, was produced in a turning converter in small charges. The melted iron having been thoroughly decarbonized by the blowing in of air, the contents of the converter were discharged into a tank of water, which had the effect of finely granulating the metal, which was

afterwards melted in crucibles with the necessary quantity of manganese.

In a letter written by Sir Henry Bessemer a few years since, there is the following reference to the early days of the Sheffield steel works, and some light is thrown on the business motives which—friendship apart—induced the Galloways to enter on the venture with him and Mr. Longsdon :

"Anxious to possess still further practical proof of the value of my invention, I made a few hundredweight of steel bars at my experimental works in St. Pancras of all the series and special qualities required in an engineer's workshop. These bars I took to the works of my friends, the Messrs. Galloways, engineers of Manchester, and, unknown to any of their people, these bars were given out and employed for all the purposes for which steel had hitherto been used in their extensive business. So identical in all its essential qualities was this steel with that usually employed by the workmen that, during two months' trial of it, not the slightest idea or suspicion that they were using steel made by a new process was ever entertained by them ; in fact, they were accustomed to use steel of the best quality, costing £60 a ton, and they had no doubt whatever but that they were still doing so.

"I may here remark that this tool steel was made from Swedish charcoal pig-iron, costing, delivered in Sheffield, £7 per ton, and it was with this high quality of raw material that our firm continued for about two years to manufacture tool steel for engineers, for which we obtained £44 per ton, and with which such firms as those of Sir William Fairbairn, Sir Joseph Whitworth, and Messrs. Sharp, Stewart & Co. were regularly supplied up to the time when larger and more profitable work had made it not worth our while to continue the manufacture of tool steel. Indeed, so satisfied were Messrs. William and John Galloway with this crucial test of our tool steel at these works that they entered into partnership as steel manufacturers with myself, my partner, Mr. Robert Longsdon, and my brother-in-law, Mr. Allen.

"We built steel works in the town of Sheffield, determined to beard the lion in his den, and to undersell the trade, until we forced them in self-defence to take a license under my patents and carry on my process. We at once got to work and dropped £10 per ton on rails. This soon brought the trade to a proper frame of mind. Sir John Brown & Co. applied for a license ; this was soon followed by Messrs. Charles Cammell & Co., and licenses were also granted to many other firms. Of course we thus created a strong rivalry to our own firm, and forced our prices down ; this we were fully prepared for, as it still left a very large margin of profit.

"Some idea may be formed of its importance as a manufacture when I state the simple fact that on the expiration of the fourteen years' term of partnership of our Sheffield firm, the works, which had been greatly increased from time to time entirely out of revenue, were sold by private contract for exactly twenty-four times the amount of the whole subscribed capital of the firm, notwithstanding that we had divided in profits during the partnership a sum equal to fifty-seven times the capital ; so that by the mere commercial working of the process, apart from the patents, each of the partners retired, after fourteen years, from the Sheffield works with eighty-one times the amount of his subscribed capital, or an average of nearly cent per cent every two months."

The Bessemer works in Sheffield soon began to repay the enterprising founders of the business, as will be seen from the statement given below, and which is taken from the books of the company.

The first two years must have been full of anxiety and discouragement, for though the works were started to teach the process, it was also a matter of great importance that they should pay.

The following are the losses and gains made during ten years, commencing with 1858 :

Year.		£	s.	d.
1858................	Loss.	729	12	2
1859................	"	1,093	6	2
1860................	Profit.	923	2	1
1861	"	1,475	10	2
1862	"	3,685	18	4
1863................	"	10,968	6	3
1864	"	11,827	0	4
1865................	"	3,949	5	11
1866................	"	18,076	18	4
1867............. ...	"	28,622	1	8

In 1868 the buildings, machinery, etc., were valued at over £34,000.

From 1860 until the present time, the career of the Bessemer works at Sheffield has been one of uninterrupted success, but they only remained the private property of Messrs. Bessemer, Longsdon, Galloway, and Allen for a period of fourteen years after the partnership entered into between these gentlemen in 1863. In 1877 the works were transferred to a public company, and remained under the management of Mr. W. D. Allen till his death in 1896. Since that time the direction has been carried on by two of Mr. Allen's sons. Concurrently with the period of prosperity that set in for the Sheffield works, that is in 1860, the iron-makers of Great Britain, realizing the advantages to be gained, took licenses under the Bessemer patents, and although the years 1860 to 1864 were full of anxiety and hard work, the battle had been won, and the strength of prejudice and hostility had been broken.

From an interesting document in my possession I have taken some facts relative to the financial position of the Bessemer process in 1862. Although, as we have seen, the prospects were excellent, the time had not then come for the payment to Mr.

Bessemer of great sums in royalties, and the expenses that had been incurred had been enormous. His faith in the future was absolutely undiminished, and, indeed, it was sustained by increasing business, but money was necessary to carry on the last phase of the struggle.

We have seen how Bessemer and Robert Longsdon, the friend of his youth, had come together, were partners, in fact, carrying on business as engineers, in Queen Street Place, New Cannon Street. It was deemed desirable by them—it was, indeed, probably a necessity—that they should dispose of a part of their patent rights, which were quite independent of the Sheffield business, to an influential group who had offered themselves as purchasers. It was a small syndicate of fifteen members, prominent among whom were John Platt, of Oldham, and the Galloways, of Manchester. For the sum of £25,000 in cash, and £25,000 in deferred payments, this syndicate acquired one-fourth share in the Bessemer process patents, the agreement holding in force from the 1st of July, 1862, to the 1st of July, 1884. This sale was effected only on the condition that Bessemer should be in no way controlled by the syndicate, but that he should have an absolutely free hand as to the regulation of licenses and the general method of conducting business. It was, moreover, decided that the firm of "Henry Bessemer and Company," of Sheffield, should be free to all royalty charges. This transaction brought the sum of £50,000 to the firm of Bessemer & Longsdon, and enabled them to pass through the last struggle. It was certainly paying a high price for the benefit, for the sums the syndicate received before the termination of the agreement must have been enormous.

XX.

The degree of development achieved in the Bessemer process up to 1863-64 is well indicated by A. L. Holley in his volume on *Ordnance and Armour*, from which I take the following extracts:

"The Bessemer process of making steel direct from the ore or from pig iron, promises to ameliorate the whole subject on ordnance and engineering construction in general, both as to quality and cost. The product has not yet been used for guns to any great extent, although Mr. Krupp, the leading steel maker, has introduced it. Captain Blakley and Mr. Whitworth have also experimented with

it, and expressed their faith in its ultimate adoption. Messrs. John Brown & Co., Sheffield, have made 100 gun forgings, some of them weighing alone 13 tons, from solid ingots of this steel. During the present year (1864) the productions of Bessemer steel will exceed 400 tons per week. With the two new converting vessels in operation, solid ingots of 20 tons weight can be fabricated. . . . The pig iron is run into a converting vessel, where it receives a blast of air for 15 or 20 minutes, to burn out the carbon and silicium. It is then cast into an ingot which is heated and forged into a gun. One remarkable piece was made for the Belgian Government, quite early in Mr. Bessemer's practice. Its dimensions were: Length of bore, 7 feet; diameter of bore, 4.7 inches; maximum diameter, 9.5 inches; thickness upwards, 2.37 inches; weight, 1,070 pounds—a very light gun. The test was three rounds with two spherical shot; three rounds with three spherical shot; three rounds with four shot; three rounds with five shot; three rounds with six shot; three rounds with seven shot, and two rounds with eight shot (the powder being 2.2 pounds in each case), when the gun broke in the bore 39 inches from the muzzle, from the wedging of the shot. There was no alteration in the chamber. . . . Among the Bessemer forgings in the Greek Exhibition of 1862 was a 25-pounder steel gun in the rough, with the trunnions formed on it. This gun was the ninety-second made by Messrs. Henry Bessemer & Co.; also a 24-pounder steel gun, bored and finished by Messrs. Fawcett, Preston & Co., of Liverpool, for whom a dozen of the same size were being made. The present English prices for Bessemer gun steel are: for a 1 ton forging, 9 cents per pound; for the same with trunnions forged on, 11 cents; for a 3 to 5-ton ingot, forged into a cylinder, 11 to 13 cents."

It is very interesting to note that at this date, 1862-64, when high authorities such as Anderson, Armstrong, and others—the smaller following, of course, obediently the greater lights—condemned steel for gun construction, and Bessemer steel for all purposes, on the ground that it was unreliable, and gave way under sudden strain, which wrought iron would resist; it is very interesting to note the certainty and accuracy with which Holley wrote. Referring to Bessemer's interesting collection of steel specimens shown at the London Exhibition of 1862, he says: "The extreme durability of the Bessemer low steel was shown by various specimens. The London *Engineer* says of one of those, that it was twisted cold into a spiral like a ribbon, and does not show a single flaw after this severe treatment." All idea of the brittleness of steel vanishes with an inspection of the example. The same authority says:

"There are also some close bends of rails, one of which is deserving special notice. Mr. Ramsbottom, the able engineer of the railway works at Crewe, had this piece taken up while covered with sharp frost, and placed under the large steam hammer, where it stood the blow necessary to double both ends together without showing the smallest indications of fracture. . . . There are also some extraordinary examples of the toughness of the Bessemer steel, made from

British coke pig-iron, among which may be enumerated two deep vessels of one foot in diameter, with flattened bottoms and vertical sides. At the top edge one of these is $\frac{3}{8}$ inch, and the other $\frac{7}{8}$ inch in thickness. A 4-inch square bar has been so twisted, while hot, that its angles have approached within less than half an inch of each other, so that what was originally one foot length of surface, has now become 26 feet, while the central portion of the bar still preserves its original length of one foot ! . . . By the present process, although the number of operations is reduced, by casting steel in large masses, its cost as compared with that of wrought iron is somewhat increased. Still it compares favorably, considering its greater strength. The present causes of the costliness of steel are principally these : Melting the metal is expensive. Such a high temperature is required, that the pots for very low steel stand only one or two meltings. The subsequent heating of immense ingots (one of Krupp's, in the great Exhibition, was 44 inches in diameter, and 8 feet long) requires time and skill; drawing them under ordinary hammers, not to speak of its injurious effects, is a very long operation. The careful preparation and selection of the materials add considerably to the cost. Again, the business is now monopolized by a few manufacturers. Standard qualities of low steel bring a price much more disproportionate than that of wrought iron, compared to the cost of production. Some of the processes are secret, others are covered by patents; but the chief difficulty is, that very few establishments out of the whole number have undertaken the manufacture. Many of the large British establishments have introduced the Bessemer process. In this country (the United States) several ironmasters pronounce this process a failure, and propose to stick to puddling and piling. At the same time others are doing all they can to develop this and similar improvements, but are indifferently encouraged. There is no doubt, however, that within a few years low steel will be produced at a cheap rate all over the world. The wonderful success and spread of the Bessemer process in England, France, Prussia, Belgium, Sweden, and even in India, all within three or four years, prove that great talent and capital are already concentrated on this subject, and promise the most favorable results."

And again :

" Among the specimens of Bessemer metal in the Exhibition of 1862, was a 14-inch octagonal ingot broken at one end, and turned at the other end, to show that the metal was perfectly solid. The turned end looked like forged steel. An 18-inch ingot, weighing 3,136 pounds, was the six thousand four hundred and tenth 'direct steel' ingot made at the works of Messrs. Henry Bessemer & Co.

" There were also exhibited, a double-headed rail, 40 feet long ; a 24-pounder and a 32-pounder cannon ; a 250-horse-power crank-shaft, and several tires without welds. The specimens showing the wonderful ductility of the metal have been referred to. The Bessemer process has been adopted during the last two or three years, since its early embarrassments were overcome, with such great success, and by so many leading manufacturers in England, France, Sweden, Belgium, and other European States, that its general substitution for all processes for making either fine wrought iron or cheap low steel is now considered certain."

I think the foregoing extracts are of great interest, because they give us a sufficiently vivid picture of the condition of the

Bessemer process, emerging from the period of difficulties and general opposition, and because they afford a remarkable illustration of Holley's keen insight and prescience, though even he would never have dreamed what the next twenty years was to see in the way of Bessemer steel-making, and towards which he was to be so largely instrumental.

At the time Holley wrote, Bessemer had indeed overcome his difficulties. His process was practically perfected, thanks to the works at Sheffield, and the many workers under his patents, in England and through Europe. The crass stupidity which deleted his British Association paper of 1856 from the *Transactions* of that body; the petty objections raised against his process, in 1859, during the discussion of his paper at the Institution of Civil Engineers; the violent hostility which his subsequent success created—all these things he could afford now to forget, although he was only on the threshold of the stupendous industrial development, the magnitude of which he could not have had the faintest conception of when he superintended the rolling of the 40-foot steel rail for the Exhibition of 1862.

XXI.

Twenty years after Mr. Bessemer had read his paper before the Institution of Civil Engineers, in addressing a meeting of the Iron and Steel Institute, he recalled some of the most interesting particulars of those early days. On that occasion, he exhibited some of the samples which he had shown to illustrate his paper in 1859. Among them was the small gun which had attracted great attention at Woolwich when Colonel Eardly Wilmot was superintendent of gun factories, and took a deep interest in the new invention, having so far satisfied himself that he supported Bessemer strongly against such opposition in 1859. He told the story of the first Bessemer steel disk which was pressed into a cup by a Mr. Parkes, the patentee of a process for pressing tubes out of copper disks. Mr. Parkes believed that the Bessemer metal would stand the test. At that time, "about 1862," Bessemer & Co. of Sheffield were making soft-steel locomotive boiler-tube plates, and from one of these plates, a disk, 23 inches diameter and three-quarters of an inch thick, was cut. It was placed on a cast-iron die, and forced half through its depth and into an opening 11 inches in

diameter; then it was annealed, and allowed to get cold, after which it was forced through the die. In this way a cup was formed 11 inches in diameter and 10 inches deep, without any cracks. Such a test must have astonished every one, even Bessemer himself, who until then had no idea of the ductility of the metal. Mr. Bessemer's story of the first application of steel rails would be spoiled unless given in his own words:

"Perhaps there was no better practical engineer in Great Britain than Mr. John Ramsbottom of the London and Northwestern Railway, and when I proposed steel rails to him, Mr. Ramsbottom, looking at me with astonishment and almost with anger, said: 'Mr. Bessemer, do you wish to see me tried for manslaughter?' That observation was the natural result of the then state of knowledge as to what could be done with steel. At that time steel was made almost exclusively for cutting purposes, and it was highly carbonized, and certainly too hard for rails. After seeing my samples, however, Mr. Ramsbottom, whose mind was thoroughly open to conviction, said: 'Well, let me have ten tons of this material that I may torture it to my heart's content. . . .' A steel rail was rolled by Mr. Ramsbottom from a portion of the ten tons mentioned, and it had been twisted cold by clamping one end in the reversing brasses of a rolling mill, and putting the other end in connection with the shaft driven by the engine, till it was twisted into two pieces. I carefully measured that sample, and I found that in a part measuring 6 feet along the centre of the web, each of the flanges measured 8 feet 1 inch. This twisted rail was a good example of what mild steel was in those days. To show that such material which twisted so well cold, would endure the hot test, a 4-inch square bar was twisted hot. It was twisted till it came in two in the centre. The angles were thus made to form a sort of screw with threads $\frac{3}{8}$ inch to $\frac{1}{2}$ inch apart."

As for the earliest application of steel to shipbuilders, Mr. Bessemer's recollections are of great interest. In 1863 Mr. Daniel Adamson had enthusiastically and successfully employed Bessemer steel for making boilers on a large scale, and it was at that time that Mr. Bessemer advocated the use of the material for ship plates. The first boat was a stern-wheel barge, built in 1863, and the following year the Humber Steam Packet Company constructed a side-wheel boat of 377 tons, of steel. The same year were finished two sailing ships, one of 1,251 and the other of 1,283 tons, and then, twelve months after, six other ships of a collective tonnage of 5,332 were completed. This was the commencement of the application of Bessemer steel to shipbuilding.

For locomotive builders it would appear that Bessemer steel was first used on the London and Northwestern Railway in 1863, by Mr. Ramsbottom and Mr. Webb, and the first boiler of this kind was kept in service until 1879.

XXII.

In Holley's work on *Ordnance and Armour*, written in 1863-64, frequent reference is made to the actual condition and future prospects of the Bessemer process, and I have already called attention to the wonderful foresight shown by Holley in his remarks as to what may be expected from it in the near future. In the same book Holley says that the Bessemer process in America was about to be tried on a practical scale by Messrs. Winslow, Griswold, and Holley. Of course the prolonged struggle and the gradual development of the Bessemer process in England had been carefully watched in the United States, but nothing practical had been done till Holley came to England in 1863, when he had many interviews with Bessemer as well as the fullest facilities given him at the Sheffield works; he had also examined and tested the specimens to which he so enthusiastically refers in his book on *Ordnance and Armour*.

Many engineers in America were, from the commencement, fully alive to the great importance of the process, and shared with English engineers the enthusiasm that attended the reading of the British Association paper in 1856. Probably they also shared the quick-following reaction and disbelief. Speaking in 1891, on the occasion of the visit to America of the British Iron and Steel Institute, Mr. Abram S. Hewitt said:

> "Mr. Bessemer read his celebrated paper describing the process of producing steel without fuel at the Cheltenham meeting of the British Association for the Advancement of Science in the summer of 1856; an imperfect report of this paper was published in the journals of the day and attracted my notice. The theory announced seemed to be entirely sound, and the apparatus simple and effective. I gave orders at once, without further information than that derived from the published report, to erect an experimental vessel for the purpose of testing the possibility of producing steel direct from the blast furnace. In the same year in which this paper was read the experiment was tried at the furnace of Cooper & Hewitt, at Phillipsburgh, in New Jersey, and the result served to show beyond all doubt that the invention of Mr. Bessemer was one that could be successfully reduced to practice."

The first experimental application of the Bessemer process was, therefore, made in America in 1856, and it is not a little remarkable that, considering the promising result obtained, nothing more should have been done with it for some years. I suppose that the energy and grand ability of Holley were required to separate the actual truth from the mass of perverted

statements and prejudice that existed in England and spread to America. During the year 1864 the United States patents of Bessemer were sold to a small American syndicate, enlarged later, I believe, and known as the Bessemer Association, Holley acting first as the negotiator and afterwards as the engineering expert. For various reasons, with which my present purpose has nothing to do, delays occurred, and those unfriendly to Bessemer in England took advantage of these delays to spread reports of failure and complications in the United States. It was under these circumstances that Holley wrote, in September, 1866, a letter in which the following passages occur:

"In view of the diverse statements of the English journals regarding the success of the Bessemer process in this country, of the improvements actually developed here, I trust that some account of our practice will be interesting. The Bessemer process was first experimentally practised in this country with a three-ton converter, at the iron-works of Mr. E. B. Ward at Wyandotte, near Detroit, under the superintendence of Mr. L. M. Hart, who had learned the Bessemer process at the works of Messrs. Jackson, in France. . . .

"Before the Wyandotte experiments were commenced, Messrs. Winslow, Griswold, and Holley, of Troy, had completed an arrangement with Mr. Bessemer and his associates for the purchase of the Bessemer patents in the United States, and had commenced the erection of a 2-ton experimental plant. This plant was started in February, 1865, and has since been in constant operation. The first ingot made had a tensile strength of 65,000 pounds per square inch in the cast state, and 121,000 pounds when hammered to a two-inch bar. A two-inch bar was bent double cold. The first ingot was a fair representative of all the steel that has since been manufactured at Troy. The pig-iron used was smelted with charcoal from the hematite and from the magnetic ores of the Lake Champlain, the Hudson River, and the Salisbury regions, and the Lake Superior iron, smelted either with charcoal near the mines, or with bituminous coal in the Mahoning Valley of Ohio. Some of the Pennsylvania and New Jersey anthracite irons produce steel equal in quality to that made from the English hematites of the Cumberland regions, but not equal to that made from the American charcoal irons mentioned. Some hundred tons of the best steel have been made from the Iron Mountain ores of Missouri, smelted with charcoal, and from the charcoal hematite irons of central Alabama. Sufficient experience has already been gained in the mixing of these various pigs to produce, uniformly, all grades of steel. The only irons that have failed are those reduced from surface ores, containing an excess of phosphorus, and those that have been smelted with very sulphurous coal. As far as tested, probably three-quarters of the American pigs produce first-rate Bessemer steel.

"Meanwhile Messrs. Winslow, Griswold and Holley had commenced the erection of a pair of 5-ton converters, and the Wyandotte works were producing a good quality of steel from the Lake Superior irons. The re-carbonizer at both works has been the Franklinite pig iron of New Jersey, which is slightly richer in manganese than spiegeleisen. . . . At the present time the 2-ton converter at Troy is producing ten tons of ingot (six charges) per twenty-four hours; the

5-ton converter will be in operation next December. The Wyandotte works are producing a smaller quantity, but a good quality of steel. Of the licensees, the Pennsylvania Steel Company, at Harrisburg, will be in operation early next year, with two 5-ton converters, a 25-inch three-high rail mill, a tire mill, a plate mill, and a forge suited to the manufacture of all ingots under 12 tons weight. Similar works at Chester, Pennsylvania, at Cleveland, in Ohio, are partially completed, and will be running during the next year. Several other works in Pennsylvania and at the West will probably produce steel within 18 to 20 months of the present writing [September, 1866]."

It is interesting to note that the plans for the Pennsylvania Steel Company's works, above referred to, were prepared in Sheffield. The converters were made by Messrs. Galloway & Sons, of Manchester; and the hammers by Thwaites & Carbutt, of Bradford; this plant was shipped in December, 1866, and was lost, with the ship, on the coast of Ireland, thus causing considerable delay.

This was the beginning of the Bessemer steel industry in the United States, described in the words of its creator. I think I echo the opinion of those who feel an interest in this subject, when I ascribe all the credit to Alexander Lyman Holley. In doing so, I in no way forget his great friends and contemporaries, and their successors, who coöperated with him from the commencement and afterwards. But it was to his genius, and energy, and patience that the Bessemer process in America was a success from the casting of the first ingot at the Troy works. It was Holley who, from the beginning and during a number of years, adapted the English details of the process to suit American requirements, and who initiated that system of rapid production, combined with a high standard of excellence, which aroused at first the incredulity, and afterwards the admiration of European manufacturers. When—some years later than the period to which we are now referring—the late S. G. Thomas visited one of the Holley Bessemer works, and, being fatigued, essayed to rest on an ingot mould, it was Holley who said to him, "You must send over to England for one cool enough to sit upon."

Although, during the preliminary stage that preceded the erection of the first Bessemer works in America, Holley was in constant communication with Bessemer, and more especially with W. D. Allen of the Sheffield works, there remains but few written records of that busy and important time. In fact, I have found nothing excepting short entries in old diaries of

Holley's frequent visits to Sheffield, and one letter which I reproduce, as it shows that the Sheffield works were Holley's training school, and W. D. Allen was his instructor:

"TERMINUS HOTEL, LONDON BRIDGE, *October* 4, 1864.

"MY DEAR SIR:

"I have come over again, to finish my education in the Bessemer process, and shall have the pleasure of calling upon you at Sheffield, with that object in view, if agreeable to you, early next week.

"I have seen Mr. Bessemer, and am glad to learn that the manufacture and the inventions are prospering so satisfactorily.

"Yours truly,

"A. L. HOLLEY.

"MR. ALLEN, H. BESSEMER & CO., SHEFFIELD.

"P.S.—Mr. Griswold, son of one of our company in the U. S. is with me, and would like to spend some time at your works, with me."

In tracing the work of Holley in the development of the Bessemer process in America, from the commencement to the year 1876, I gladly make use of the admirable paper read by Mr. Robert W. Hunt before the American Institute of Mining Engineers, in June, 1876. This paper is entitled: "A History of the Bessemer Manufacture in America," and is full of interesting information. In one paragraph Mr. Hunt defines exactly the secret of Holley's wonderful progress and success.

"After building the first experimental works at Troy, Mr. Holley seems to have at once broken loose from the restraints of his foreign experience, and to have been impressed with the capabilities of the new process. The result is that mainly through his inventions and modifications of the plant, we in America are to-day enabled to stand at the head of the world in respect of amount of product."

Mr. Hunt's statement, made twenty-two years ago, can be applied with greater force to-day. The same authority summarizes the modifications and improvements made by Holley:

"He did away with the English deep pit, and raised the vessels so as to get working space under them on the ground floor; he instituted top-supported hydraulic cranes for the more expensive English counterweighted ones; he put three ingot cranes around the pit, instead of two, and thereby obtained greater area of power. He changed the location of the vessels, as related to the pit and smelting house. He modified the ladle crane, and worked all the cranes and the vessels from a single point; he substituted cupolas for reverberatory furnaces, and last, but by no means least, introduced the intermediate or accumulative ladle, which is placed on scales, and thus insures accuracy of operation, by rendering possible the weighing of each charge of melted iron, before pouring it into the converter. These points cover the radical features of his innovations. After

building such a plant, he began to meet the difficulties in manufacture, among the most serious of which was the short duration of the vessel bottoms, and the time required to cool off the vessel to a point at which it was possible for workmen to enter and make new bottoms. After many experiments the result was the Holley vessel bottom, which either in its form as patented, or in a modification of it, as now used in all American works, has rendered possible as much as any other one thing, the present immense production. Then he tried many forms of cupolas at Troy, adopting in the original plant a changeable bottom, or section below the tuyeres; then later at Harrisburg, assisting Mr. S. B. Pearse, in developing the furnace to a point which rendered the many bottoms unnecessary, chiefly by deepening the bottom and enlarging the tuyere area. Upon his rebuilding the Troy works after their destruction by fire, Mr. Holley put in the perfected cupolas. At this time the practice was to run a cupola for a turn's melting, which had reached eight heats or forty tons of steel, and then dropping its bottom. This was already an increase of 100 per cent. over his boast about the same amount in twenty-nine hours."

Of course all these modifications were gradual, the result of experience during the fourteen years ending in 1876. But what also contributed largely to the wonderful output from American Bessemer works was the enthusiasm of Holley, which he had the gift of communicating to all these who worked with him, his wonderful energy and his power of organization. There were fourteen very busy years which ended with 1876, the gross result of which was that the production of steel in the United States was 550,000 tons of ingot, about one-tenth of what it is to-day. Until that date, and, indeed, until the time of his lamented and premature death, no Bessemer works were built in America without Holley's direct and personal coöperation. We have seen how he completed the Troy works in 1864; the Pennsylvania Steel Works followed in 1867; the Troy works were rebuilt in 1868. Counting the Wyandotte works, the Pennsylvania Co.'s was the third in the United States. The Freedom Iron and Steel Works, near Lewistown, Pa., were the fourth—they ran their first charge in May, 1868. The Cleveland Rolling Mill Co.'s Bessemer works, also in 1868, were the fifth. The Cambria Iron Co., Johnstown, Pa. (1871), came sixth; the Union Iron Co. of South Chicago (1871), were seventh; the North Chicago Rolling Co., Chicago, were the eighth works—they commenced operation in 1872. The Joliet Iron and Steel Co., Joliet, Ill., formed the ninth Bessemer plant, erected in 1873. The same year the tenth works was completed by the Bethlehem Iron Co. of Pennsylvania; the Edgar Thomson Steel Co. of Pittsburgh erected the eleventh Bessemer works in 1875;

the twelfth were completed by the Lackawanna Iron and Coal Co. in May, 1876.

Since that date the extensions have been enormous, and the efficiency of plant has vastly increased, as will be seen from the following list, taken from Swank's *Directory of American Iron and Steel Works*, 1898:

LIST OF WORKS IN UNITED STATES WITH BESSEMER STEEL CONVERTERS.

	No. and Capacity of Converters.		
Fremont Rail Works Co., West Wareham, Plymouth Co., Mass...	4	3	ton
Troy Steel Co., Troy, Rensselaer Co., N. Y.	3	15	"
Jones & Laughlin's, Ltd., American Iron and Steel Works, Pittsburgh, Pa.	2	10	"
Bethlehem Iron Co., Bethlehem, Northampton Co., Pa.	4	7½	"
Birdsboro Rail Works (E. and G. Brook Iron Co.), Birdsboro, Berks Co., Pa.	2		
Cambria Iron Co., Johnstown, Cambria Co., Va.	4	11½	"
Carnegie Steel Co., Ltd., Pittsburgh, Pa. (Duquesne, Alleghany Co.)	2	10	"
" " " (Edgar Thomson Steel Works)	4	15	"
" " " (Homestead Works, Munhall)	2	10	"
Columbia Iron and Steel Works, Uniontown, Fayette Co., Pa.	2	5	"
Lackawanna Iron and Steel Co., Scranton, Lackawanna Co., Pa. (North Works)	3	7	"
Lackawanna Iron and Steel Co., Scranton, Lackawanna Co., Pa. (South Works)	2	9	"
Lickdale Iron Works, Lickdale, Lebanon Co., Pa.	2	3	"
National Tube Works Co., McKeesport, Allegheny Co., Pa.	2	8	"
North Branch Steel Works, Danville, Montour Co., Pa.	2	4	"
Oliver and Snyder Steel Co., Pittsburgh, Pa.	2	5	"
Pennsylvania Steel Works Co., Steelton, Dauphin Co., Pa.	3	10	"
Pottstown Iron Works Co., Pottstown, Montgomery Co., Pa.	3	10	"
Shenango Valley Steel Works Co., Newcastle, Lawrence Co., Pa...	2	8	"
Shoenberger Steel Co. (Juniata Iron and Steel Works), Pittsburgh, Pa.	2	6	"
Spang Steel and Iron Co., Pittsburgh, Pa.	2	3	"
Wellman Steel Works, Thurlow, Delaware Co., Pa.	2	3	"
Woodson's Steel Co., Pittsburgh, Pa. (Contemplated)	2	8	"
Maryland Steel Co., Sparrow's Point, Baltimore Co., Maryland....	2	20	"
Old Dominion Nail Works Co., Richmond, Henrico Co., Va.	2	3	"
Riverside Iron Works, Benwood, Marshall Co., West Va.	2	6	"
Wheeling Steel Works Co., Benwood, Marshall Co., West Va.	2	6	"
Ashland Steel Co., Incorporated, Ashland, Boyd Co., Kentucky...	2	5½	"
Etna Standard Iron and Steel Co., Mingo Junction, Jefferson Co., O.	2	10	"
Bellaire Steel Co., Bellaire, Belmont Co., O.	2	10	"
Cleveland Rolling Mill Co., Newburgh, Cuyahoga Co., O.	2	10	"
Johnson Co., Lorain, Lorain Co., O.	2	12	"
King, Gilbert and Warner Co., Columbus, Franklin Co., O.	2	4½	"
Ohio Steel Co., Ltd., Youngstown, Mahoning Co., O.	2	10	"

	No. and Capacity of Converters.	
Otis Steel Co., Ltd., Cleveland, Cuyahoga Co., O.	2	5 ton
East Chicago Steel Works, Hammond, Lake Co., Ind.	2	3 "
Premier Steel Co., Indianapolis, Marion Co., Ind.	2	4 "
Union Steel Co., Alexandria, Madison Co., Ind.	2	5 "
Illinois Steel Co., Rookery Building, Chicago, Ill., North Works, Chicago	2	6 "
Illinois Steel Co., South Works, So. Chicago	3	10 "
" " " Joliet Works, Will Co.	2	9 "
" " " Union Works, Chicago	2	10 "
Springfield Iron Co.'s Works, Springfield, Ill.	2	5 "
Detroit Steel and Spring Works, Detroit, Mich.	2	2 "
West Superior Iron and Steel (Wisconsin Steel Co.), West Superior, Douglas Co., Wis.	2	4 "
Colorado Fuel and Iron Co., Bessemer, Pueblo Co., Colo.	2	5 "

XXIII.

By the year 1866 business was quite flourishing at the Sheffield works of Henry Bessemer & Co., and the amount of royalties Bessemer received was already large. Opposition had been to a great extent silenced, partly because many important licensees were engaged in the manufacture, and partly because facts were too strong even for the most unscrupulous opponents. Moreover, it is certain that the powerful syndicate which had purchased one-fourth share of the patents strengthened Bessemer's position greatly. The time, however, had not yet come for the most general application of Bessemer steel—its application to railway tracks all over the world. Prices were still high, though not so high as appeared likely a few years before, when the Institution of Mechanical Engineers held their meeting in Sheffield, and Mr. Bessemer read a paper on his process before it. Even at that time (1861) the success of the process could not be denied, but, at least, it was possible to assert that the price of the steel produced was, and must always remain, prohibitive. Mr. John Brown, of Sheffield, maintained at the meeting that the price could not fall below £22 per ton; many other persons whose opinions carried weight held the same opinion when Holley wrote his book on *Ordnance and Armour*, from which I have already quoted; but, as we have seen, Holley was too clear sighted to believe any such thing. There were far-seeing people in England who believed it was only a question of time for Bessemer steel to supersede iron on all railroad

tracks. In 1862, Mr. Ramsbottom, of the London and Northwestern Railway, had purchased an ingot from Sheffield, had rolled part of it into a rail, and laid it outside the goods station at Camden on the 9th May, 1862, the opposite rail of the same track being of a standard iron section. Nearly two and a half years after—in September, 1864—it was taken up and examined. It was estimated that ten million truck wheels had passed over it; it had never been turned (it was a double-headed rail), and it had worn out seven iron rails, that is, fourteen surfaces, during that time. The test at Crewe, however, was earlier than this. Crewe station was laid with steel rails, rolled from ingots made at Sheffield in 1861. Three hundred trains ran daily through the station, but in 1866 these rails had never been turned, and they were all in good order. They had been rolled in 35-feet lengths. Experiences like these rapidly prepared the way for the great change that was approaching. It could be demonstrated that, even at the high price, their long life made steel rails much cheaper than iron ones. The cause of occasional failure by fracture of steel rails was so easily traced to the production of too hard a metal, that it could not be urged in absolute condemnation of the system. The Metropolitan Railway Company was among the early purchasers on a considerable scale. They bought in large quantities in 1865, at a price of £17 a ton, though the next year the rate fell to £12 a ton. And this fall in price occurred in face of a £2 per ton royalty; that is, the royalty was £2 per ton of ingots cast, with a drawback of £1 per ton of rails rolled.

The year 1865 was indeed a busy one in England and through Europe for Bessemer steel making. Many large establishments had been already preparing for a year or two, and were then ready to fill orders. As we have already seen, Holley was occupied in America, having "completed his education" at Sheffield. In France a comparatively large amount of Bessemer steel rail had been made and laid down. Amongst other steel works on the continent at that date there were, in Germany, the Essen Works, of Krupp; the Bochum Company, with four 3-ton converters; the Hoerde Company, near Dortmund, with two converters; the Neuberg Works, in Styria, with one converter; the Gratz Works, with one; the Witkowitz Works, with one; the works at Düsseldorf with two. Among other works were divided twelve converters. In France and Belgium the

process was in operation at John Cockerill, of Seraing; at Petin, Gaudet & Co., Rive de Gier, and at James Jackson & Co., St. Severin, near Bordeaux.

In England the Bessemer steel rail trade was growing rapidly, and the demand for steel plates was also increasing. One firm had rolled, in 1865, 5,000 tons of steel plates, to a maximum weight of 16 hundredweight, and measuring 13 feet 4 inches by seven-sixteenths thick. It was provided in the specification to which these plates were made, that they must be of such a quality that disks cut from them could be stamped up cold into vessels 10 inches diameter and 11 inches deep without showing signs of fracture.

I do not know what the production of steel was in England in 1865, but on the continent it is stated to have been as follows: France, 30,000 tons; Prussia, 33,000 tons; Belgium, 4,000 tons; Austria, 21,000 tons; Russia, 5,000; Sweden, 6,000; the German States, 2,000; Italy, 750; and Spain 500 tons.

The industry acquired a great momentum in 1866, and some of the good old days of high prices had gone never to return. In 1860, Krupp, of Essen, was able to command £120 per ton for steel tires; in 1866 Bessemer & Co., of Sheffield, had forced this price down to £40 and £45 per ton. In 1866, and for several years after, royalties poured in on Bessemer, amounting to as much as £200,000 a year; this came chiefly, though of course not wholly, from rails. His day of triumph had come, his financial success was as great as the confusion of his enemies was complete. At this time, and for some years after, the United States proved a rich market to English steel rail producers. Leading American railroad directors were so keenly alive to the advantages of steel, that they would not wait for the completion of the works Holley was building, but decided to buy meantime in England. In 1866 the first order of steel rails came from America. It was sent by the Erie Railroad Co. to Messrs. John Brown & Co., for 1,000 tons at £25 a ton; then followed the Pennsylvania Railroad Co., with an order to the same makers, and at the same price, for 500 tons. The cost of wages at that time per ton of rails was £2. In 1866 Messrs. John Brown & Co. were the largest makers of Bessemer steel; they had become licensees about 1862, and four years later they were running constantly two 10-ton converters, and two of 5 tons. They employed 3,000 men, and their plant was capable of rolling

30-ton ingots into single plates. They had gone largely into the steel tire business, and, as we have seen, had brought the price of Krupp steel tires to one-third of what it had been six years before. Rails, of course, formed the chief part of their output, but they were doing a large trade in steel axles. In 1866 the rival firm of Messrs. Cammell & Co., of Sheffield, had quite large Bessemer works (for the time), comprising two 4-ton converters, and four of 7 tons; they were making 500 tons of steel a week. During the same year 63 miles of steel rails were laid on the London and Northwestern Railway. In 1867 the works at Barrow-in-Furness were in full operation, with six 7-ton converters; the Lancashire Steel Co., at Gorton, had four pairs of 5-ton converters, and several other companies were started. On the continent the progress was as rapid, especially in France, and by 1867 the price had dropped to £12 per ton, at which price 28,000 tons were sent from England to the United States. In Johnstown, Pennsylvania, £12 9s. was the cost of making iron rails per ton; in England such rails cost £6 per ton. Prices were falling in 1867, though in that same year the Styrian Bessemer works commanded £16 per ton for ingots, £28 10s. for bars, £30 per ton for boiler plates, and £32 for tires.

The time for the very profitable business of exporting Bessemer rails to America was to last only a few years longer, for Holley's work was progressing rapidly, and large orders could be filled from the seven steel works he had in operation by the middle of 1868. Still a large portion of the 5,000 tons of rails laid that year by the Erie Railroad Co., came from England.

The golden harvest had been gathered by Bessemer at the end of 1868, for his leading patent expired on the 12th of February, 1869, and the royalty dropped to 2s. 6d. per ton, which made a saving of about 20 shillings per ton on all rails made. A great impetus was in consequence given to the production and demand. In France during that year 40,000 tons were rolled, of which 5,000 tons went to America, where steel rails were being laid at a great rate, regardless of the higher cost, which, indeed, was not relatively high, on account of the great price of iron rails. In 1869 there were 110,000 tons of steel rails laid on United States railways; of this quantity, Cammells exported 27,000 tons; John Brown & Co, 50,000 tons, and Barrow 15,000 tons. But the Troy works were now able to turn out at the rate of

20,000 tons a year. In this country, the Great Northern Railway Co. was still conservative; in January, 1869, it advertised for tenders for 200 tons of steel, and for 5,000 tons of iron rails.

So far as our present purpose is concerned, we need not follow the growth of the Bessemer process after the expiring of the 1855 patent, which terminated the period of great royalties. The struggle of the earlier years had been so long prolonged that it left but little time for getting repaid. The success, when it arrived, was enormous, though it was very brief, but Bessemer could afford to look back on the past, satisfied with the result achieved, and to the future, certain that the vast industry he had created would continue to grow indefinitely, though to what extent he could not foresee. It may be said that by 1874, when the Sheffield works were converted into a public company, Bessemer had retired from business, though his interest in watching the development of the process, especially in the United States, never lessened.

That the Bessemer patents were financially successful during the years 1862–70, and that to a remarkable degree, is evident from the fact that Sir Henry received in royalties during a part of that time no less than £200,000 a year. But the sum received did not represent so large a total as may be imagined. It is stated that by 1870, royalties had been paid to the extent of a million sterling. Of this £250,000 were the property of the syndicate that had purchased one-quarter ownership of the patents in 1863 for the sum of £50,000. The remaining £750,000, less many reductions, was the joint property of Sir Henry Bessemer and his partner, Mr. Longsdon. As profits on patents go, the result was very exceptional; moreover, it was attained—not in the modern method, by company promotion—but by continuous and well-directed work, and by the sacrifice of a large income derived from the bronze powder industry. As to the results achieved to the world at large, they can be estimated only by the amount of steel that has been manufactured since the first charge of pig was decarburized in the small experimental converter at Baxter House.

XXIV.

I have sketched very rapidly and imperfectly the development from 1859 to 1869, when the chief Bessemer patent expired, and it would be quite outside the purpose of this monograph to

attempt any history of its growth from then until now. During the twenty years that followed the expiring of the 1855 patent, the manufacture of Bessemer steel had increased, until in 1890 the estimated output was ten millions per annum. And we have already seen that the capacity of American production alone is, for this present year, about 9,500,000 tons. From quite an early date the manufacture of steel in the United States has exceeded that of any other country, and I do not think it is an over-estimate to say that its capacity now exceeds the produce of all the rest of the world collectively. As the output has increased, prices have fallen, until they have now reached the lowest point on record, about £5 per ton for rails. That is to say, that the invention of Bessemer represents to-day a possible total of money value of £50,000,000 sterling on the output of the converters in the United States.

These gigantic figures are beyond our grasp, and we have to turn to Sir Henry Bessemer's vivid method of dealing with large amounts to comprehend what they mean. In an often quoted letter to the *Times*, published some time in 1893, Bessemer brought these figures down to the intelligence of the average reader. The passages are so interesting that I may be pardoned for reproducing them once more. He dealt with the world's estimated output in 1892—10,500,000 tons.

"Let us," he wrote, "use the mind's eye to assist us, and imagine standing erect before us a plain round column or tower of solid steel 20 feet in diameter, 400 feet high; this, no doubt, would impress us as a very large and heavy mass, and few people would be prepared at first to accept the simple fact that the production of Bessemer steel in 1892 would make 1,671 such columns, and leave a remainder of 5,535 tons. Yet such is the fact. These tall columns would form a goodly row, and if placed side by side in a straight line, and in contact with each other, would extend to a distance of 6 miles and 580 yards; indeed, there is on an average 5.3 such columns produced on each working day in the year, bringing up each day's production of steel to 33,546 tons, as compared with Sheffield's former production of 51,000 tons annually.

"We may put this in another way, and imagine a plain cylindrical column of 100 feet in diameter, a good idea of which may be formed by a glance at some of the very large gasometers in the metropolis; then further imagine this gasometer, not as a thin iron shell, but as a ponderous solid mass rising before you to an altitude of 6,654 feet 6 inches, or nearly one mile and a third in height. Such a huge solid mass would be exactly equal to one year's make of Bessemer steel. But even in this form we must draw powerfully upon our imagination, for but few people can, in their mind's eye, fully realize a huge solid mass of such heavy matter rising to more than 16½ times the height of the cross of St. Paul's.

"It must be remembered that the process of converting crude iron into steel

goes on ceaselessly in the converter for the whole twenty-four hours of each day, so that one hour's production is only one twenty-fourth part of a single day's work; but if all the steel produced in the Bessemer converter in this short interval of time were collected, it would form a solid cylindrical mass of 8 feet in diameter, and 139 feet in height, thus overtopping the Duke of York's column and the Nelson monument. What a notable portico would twenty-four such columns make, the work of a single day, but yet large enough to dwarf the grand old ruins of Karnac and Thebes.

"It may be interesting to put this matter in another form, in order to bring it vividly home to the imagination. A steel ingot of one ton weight is as nearly as possible 5 cubic feet in solid matter. Let us now imagine a solid square ingot of solid steel, having a base measuring 50 feet by 50 feet and standing, say, 400 feet high. This would make a square tower of solid steel much larger than the Clock Tower of the House of Parliament, which is precisely 40 feet square, and about half as high as this imaginary square tower; in fact, such a tower would only be about 4 feet below the top of the cross of St. Paul's Cathedral. This tower would contain precisely 1,000,000 cubic feet, and would weigh just 200,000 tons. Now, the Thames embankment, from Westminster Bridge to Blackfriars Bridge, measured down the centre of the roadway, is one mile and a quarter and a few yards. Let us suppose one of those gigantic towers to stand opposite the Clock Tower, and in a line with the roadway over Westminster Bridge, and a similar one erected at the other end of the embankment in a line with the roadway passing over Blackfriars Bridge. Let us further imagine fifty other precisely similar towers placed equidistant between them, thus leaving a space of only 27 yards between each tower. This row of gigantic towers would represent 10,400,000 tons, or just 100,000 tons less than one year's production of Bessemer steel, each of the 52 towers being 1,923 tons less than the average production.

"We might think of many other object lessons that would be likely to convey to the mind's eye a vivid and realistic picture of the enormous bulk of matter represented by 10,500,000 tons of steel. Let us select one other illustration. Imagine a straight wall 100 miles in length, 5 feet in thickness, and 20 feet in height. Such a wall would stand on 60½ acres of land; but suppose that this wall, like a gigantic armour plate, was formed into a circle and used to surround London; the enclosure so made would extend to Watford on the north, to Croydon on the south, to Woolwich on the east, and to Richmond on the west. It would, in point of fact, form a circular enclosure of 31¾ miles in diameter, and would embrace an area of 795 square miles. This great wall of London would just be equal to a single year's production of Bessemer steel.

"The great financier who is constantly dealing with the realised values of many millions would have a very keen appreciation of what 84,000,000 pounds sterling really means, yet I doubt if even the Chancellor of the Exchequer could, off-hand, give anything like the correct dimensions of a mass of standard gold of that value. It can, however, be ascertained with accuracy. Since 57 sovereigns weigh just one pound avoirdupois, the weight of 54,000,000 sovereigns would be 657 tons, 17 hundredweight, 3 quarters and 16 pounds, and as the specific gravity of standard gold coin is 17.167, we should have a mass equal to 1,374.70 cubic feet, from which one could make a plain cylindrical column of solid gold 5 feet in diameter and 109 feet 5 inches in height, as a representative of the commercial value of the larger column of steel which I have referred to. It is an interesting fact that the statistics published by the *Annales des Mines* for 1893 show that it would take more than three years' production of all the

gold mines in the world to pay in gold for one year's production of Bessemer steel."

The data upon which Sir Henry Bessemer founded the foregoing curious calculations in 1893 apply—except as regards price—very nearly to the capacity of the United States Bessemer works for 1895-1899. Those who are sufficiently interested, can extend the computation to the world's output of the current year.

XXV.

In 1871-72 Bessemer's energy had found a new object—that of the swinging saloon for sea-going vessels. This object he pursued very seriously for some years. During the whole of his long life, Sir Henry Bessemer traveled but rarely beyond the limits of the United Kingdom, for the simple reason that he suffered more than most people from sea-sickness. It was this unconquerable malady which directed his thoughts to a means of reducing the movements of passenger cabins at sea, which resulted in the costly experiment of the steamship "Bessemer." This ship, which was designed and constructed under the advice of Sir E. J. Reed, was intended for the Channel service, between Dover and Calais. She was 350 feet long and 40 feet beam, increased to 54 feet by a row of overhanging staterooms on each side between the two sets of paddle wheels, which were placed 106 feet apart. There were two sets of independent engines, indicating together 4,000 horse-power, and the four side wheels were each 30 feet in diameter. The length of the promenade deck was 270 feet, there being a low deck at each end, 40 feet long, for the capstans and other ship's gear. The great feature of the ship was, of course, the Bessemer swinging saloon, placed amidships; it was 70 feet long; 30 feet wide, and 20 feet high, and it weighed 180 tons. No money or trouble was spared to make this saloon luxurious in fittings, ventilation, warming, etc. The whole structure was hung, fore and aft, on two trunnions, the massive bearings for which were built into the ship's frames. The saloon was carried on steel transverse girders, the ends of the central pair of which projected beyond the sides of the saloon, and were connected to a pair of vertical hydraulic cylinders and plungers; diagonal hydraulic cylinders were also connected to the underside of the floor framing. All of these

controlling cylinders were connected, by a system of piping, to a regulating station on deck, where an operator could, by the mechanism provided, so govern the relative position of the hydraulic cylinders and the rams, that the saloon could always be kept horizontal. The mechanism all worked admirably, but of course it was only efficient in counteracting the roll of the ship; it was powerless against the effect of pitching, or of the rise and fall of the ship in rough water. Those who may be interested in this experiment should refer to Sir E. J. Reed's paper on the "Bessemer Steamship," read before the Institution of Naval Architecture in April, 1875. Referring to the limited efficiency of the "Bessemer" saloon just mentioned, Sir E. J. Reed said:

"Mr. Bessemer's idea was, and is, to apply his machinery not only to the transverse motion of the saloon or cabin, but also to the longitudinal oscillation. But as this vessel was intended only for Channel service, and as it was to be a large vessel, performing the service in comparatively small waves, it was thought desirable by Mr. Bessemer, as well as by his friends, that he should limit the first application of his system to the removal of transverse oscillation."

On Saturday, the 8th May, 1875, the "Bessemer" made her first and only public trip from Dover to Calais, in quite calm weather. The trial was not successful; despite her relatively high engine power she was slow, taking one hour and thirty-three minutes in the crossing; she steered badly (or perhaps too well), and was only got alongside at Calais after having carried away 100 feet of the pier head. The swinging saloon was not operated, on this occasion, partly on account of the calm sea, and partly because the gear was not completely adjusted. The return trip was unsatisfactory as regards speed—one hour and forty-four minutes.

Previous to this run, the "Bessemer" had made two trial trips, and had once done damage to the pier. The opinions of experts were strongly opposed to her being placed on the service, and to all practical purposes her career ended with the return journey to Dover on Monday, May 10, 1875. The failure was a great disappointment to Sir Henry Bessemer, who paid all the expenses incurred by the small syndicate that had been formed to build the vessel.

The later years of Sir Henry Bessemer were years of busy leisure. He erected a fine observatory at his residence on Denmark Hill, and devoted a great deal of time to the construction

of a telescope, and to mechanisms for grinding and polishing lenses. From this he was led to a series of interesting experiments on the application of solar heat for the production of high temperatures, and he hoped to do much with his solar furnace. He laid out, with his usual originality and skill, a diamond-cutting and polishing plant for one of his grandsons, whom he had established in that industry; and he continued to the last to take a keen interest in his very beautiful house and grounds, where he resided for many years, and which showed in every direction evidences of his great artistic skill and his mechanical ingenuity. During six or seven years before his death he was occupied in a somewhat desultory manner upon his Autobiography, a work he had practically completed, and which it was his earnest desire should be published promptly. In this book is told, in detail, the story I have sketched only very generally and imperfectly, and in doing which I have probably made some errors and omissions, for I have preferred to depend wholly on other sources of information in the pages which I now submit to your Society.

XXVI.

Sir Henry Bessemer's name is among the founders of the Iron and Steel Institute in 1868, as one of the representatives of the Sheffield district, on the provincial committee. He followed the Duke of Devonshire as president of the Institute during the years 1871-73. Although his name appears probably more frequently than that of any one else in the volumes of *Transactions*, he only contributed two papers besides his presidential address. The first of these was in 1886, and was entitled, "On Some Earlier Forms of Bessemer Converters." The second paper was read in 1891, "On the Manufacture of Continuous Sheets of Malleable Iron or Steel direct from the Fluid Metal." This suggested process was to some extent a development of his early patents for a similar treatment of fluid glass. But though he contributed only two papers to the Institute, he took a lively interest in its proceedings, was a constant attendant at the meetings, and very frequently took part in the discourses.

In 1873, on retiring from the presidency, Sir Henry Bessemer invested the sum of £400 in perpetual debentures of the Lon-

don and Northwestern Railway, to furnish funds for the annual provision of a gold medal to be awarded at each annual meeting of the Institute.

"The awards are to be (1) to the inventor or introducer of any important or remarkable invention, employed in the manufacture of iron or steel; (2) for a paper read before the Institute, and having special merit and importance in connection with the iron and steel manufacture; (3) for a contribution to the Journal of the Institute, being an original investigation bearing on the iron and steel manufacture, and capable of being productive of valuable and practical results. The Council may, in their discretion, award the medal in any case not coming strictly under the foregoing definitions, should they consider that the iron and steel trades have been, or may be, substantially benefited by the person to whom such an award is to be made."

The Bessemer medal is a much-coveted distinction, and the recipients since 1874 have not only been distinguished in the iron and steel industries, but have fully complied with conditions imposed by the Council. Twenty-eight medals in all have been given; in 1883, 1884, 1889, and 1890, two such distinctions were awarded. The names of the recipients are as follows:

1874. Sir Lowthian Bell, F.R.S.
1875. Sir William Siemens, F.R.S.
1876 Robert F. Mushet.
1877. John Percy, M.D., F.R.S.
1878. Peter Ritter von Tunner.
1879. Peter Cooper.
1880. Sir Joseph Whitworth.
1881. William Menelaus.
1882. Alexander Lyman Holley.
1883. George J. Snelus, F.R.S.
1883. Sidney Gilchrist Thomas.
1884. Edward Windsor Richards.
1884. Edward P. Martin.
1885. Richard Akerman.
1886. Edward Williams.
1887. James Riley.
1888. Daniel Adamson.
1889. John D. Ellis.
1889. Henri Schneider.
1890. William Daniel Allen.
1890. Hon. Abram S. Hewitt.
1891. Rt. Hon. Lord Armstrong, C.B., F.R.S.
1892. Arthur Cooper.
1893. John Fritz.
1894. John Gjers.
1895. Henry M. Howe.
1896. Hermann Wedding.
1897. Sir Fred. A. Abel, F.R.S.
1898. Richard Price-Williams.

It will be noticed that the names of several distinguished Americans occur in the foregoing list, notably that of Alexander Holley, who died before the date of presentation. Among the other recipients I may dwell for a moment on that of W. D. Allen, Bessemer's brother-in-law and life-long associate. His name has occurred so often in the course of this sketch, and the part he played in the development of the Bessemer process was so important, that I think the subjoined letter, written by Sir

Henry to Mr. Allen, will be read with interest. The letter is dated April, 1890:

"There was a Council meeting this morning of the Iron and Steel Institute, and among other business, we had to decide the question of the award of the Bessemer medal. I addressed the meeting, and said I had made it a rule not to throw any weight into this question, but preferred that my fellow Councilmen should take the initiative, but at the same time observing that this standing aloof might be carried too far, and a great injustice done, and under these circumstances, I said that I felt, in duty bound, to name a gentleman to whom the introduction, and the successful carrying out, of the Bessemer steel process, was very greatly indebted, and that I was the more able to bear testimony in his behalf, because, although once intimately associated with him in business, I had for the last dozen years ceased to have any pecuniary interest whatever in the works referred to.

"I said that Mr. W. Allen, of the Sheffield Bessemer steel works, assisted me in the very first experiments I ever made, and became thoroughly initiated in all facts that related to the process; that he assisted in the building and laying out of our Sheffield works, and had the entire management of the process as well as of the business, and in that capacity realised almost fabulous profits from an extremely small capital. Further, that in aid of the introduction and dissemination of the 'art and mystery,' he had done a great deal, all the early makers having derived from him that stock of knowledge with which they commenced their respective business; and further, that Mr. Allen had introduced many important improvements in the detail of manufacture.

"I also remarked that it had been frequently said, that Bessemer steel was very good for rails, but not for a higher class of goods. Now Mr. Allen had conclusively proved the contrary of this assertion; he had never made a rail, but had gone in for the better class of material now so largely used in the Sheffield manufactures. He produced a high class of Bessemer steel, which was fully appreciated by the Sheffield trade, and he consequently was enabled to realise most remunerative prices, in proof of which I might mention the fact that a few weeks ago, Messrs. Bessemer & Co. (which is mainly Mr. Allen and his son) declared a dividend of 25 per cent. per annum, on a capital of £90,000; carried £23,000 forward; wrote off £5,000 depreciation; and spent out of revenue £11,000 in new erections. Such a result, in the face of the great competition in Bessemer steel, is, I take it, a strong proof of the excellence of the material of which Mr. Allen has acquired the art of making.

"Mr. Windsor Richards spoke of the valuable information he had received from Mr. Allen; Mr. Snelus made a similar statement, and Mr. Ellis confirmed the fact of your success as a manufacturer of high grade Bessemer; the question was then passed, and you were unanimously awarded the Bessemer medal, which is to be presented to you at the May meeting. This award has given me a great deal of satisfaction. . . . I do not know if you are aware that I have been engaged in designing and superintending the execution of a very handsome diploma, framed and glazed, to be presented to all who have been previously awarded the medal; a dozen of these will be sent out to-morrow. . . . It was thought that the medal itself can be rarely shown, and that this large and beautifully got up design might be hung up in a library or in the principal office of the medallist, where the fact would show itself to all who came, whereas the medal itself was generally locked up for safety."

Sir Henry Bessemer contributed but few papers to the technical societies. Besides the two above mentioned as having been read before the Iron and Steel Institute, and his presidential address, delivered to the same body, I am aware of only few other papers, though no doubt there are some that have escaped my notice. There is the famous British Association paper of 1856; the Institution of Civil Engineers paper of 1859; a paper read before the Institution of Mechanical Engineers in 1861; and the paper read before your own Society, some two years since.* The contributions which he made to technical literature are all pleasant reading, and one regrets that he was not a more prolific writer.

XXVII.

Considering the great service Bessemer rendered to the whole world, the recognitions he received were few and insignificant. The decoration of the Legion of Honor, offered him by the French Emperor about 1856, he was not permitted to accept; the tardy acknowledgment by the British Government, of his great service rendered to the Inland Revenue Office, did not come to him in the form of a knighthood till 1879. He was made a Fellow of the Royal Society of Great Britain also in 1879, and previous to that time he had received the decoration of Commander in the Order of Francis Joseph, from the Emperor of Austria. He was, as we have seen, President of the Iron and Steel Institute in 1871, and was made a member of the Institution of Civil Engineers in 1877. He was an Honorary Member of your Society, and received many medals and diplomas of honorary membership from various European institutions.

In April, 1880, the freedom of the Company of Turners was presented to Sir Henry Bessemer, and on Wednesday, October 5, of the same year, the freedom of the City of London was also presented to him, "in recognition of his valuable discoveries, which have so largely benefited the iron industries of the country, and his scientific attainments, which are so well known and appreciated throughout the world."

In the course of his speech, thanking the city for this mark of appreciation, Sir Henry said:

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* *Transactions* A. S. M. E., vol. xviii., p. 455, No. 720.

"Under the process which I had the honor of inaugurating we dispense with every one of the intermediate processes formerly employed. We have no smelting of pig iron, we have no making of balls, we have no rolling of bars, we have no shearing of bars, we have no piling up, we have no heating furnaces.

"You will readily understand why, with a process so rapid, and so entirely devoid of the use of expensive fuel, and of all those varied skilled manipulations which were necessary at every stage in the old process, the cost of manufacture is so exceedingly small as it is found to be. . . . At the time when my invention was introduced into Sheffield the entire make of steel was 51,000 tons a year; last year we made 830,000 tons of Bessemer steel, being sixteen times what was before the entire output of the whole produce of the country. It is anticipated that on the continent of Europe this year's make will reach in all 3,000,000 tons. The value of these 3,000,000 tons together may be taken at £10 per ton, or £30,000,000 sterling, and if that metal had been made by the old process which I have described, it would have been impossible to have brought it into the market under £50 a ton, or £150,000,000 sterling."

Of all the distinctions bestowed upon Sir Henry Bessemer, that which he most appreciated was the compliment paid him in the United States by naming more than one of your cities after him.

The original of the portrait that accompanies this monograph hangs on one of the walls of the Society's building. It was presented by Sir Henry Bessemer in 1890, and I had the pleasure of bringing it to you on the occasion of my visit in 1890. Sir Henry asked me to be the bearer of this picture, and of a letter, from which I make the following extracts, because they show his deep appreciation for the esteem in which you held him. He wrote:

"It is a source of great regret and disappointment to me that Nature has interposed an inseparable barrier between us, by giving me a constitution that does not permit me to make the shortest sea voyage without absolute danger of life; but for this circumstance the fact of my being in my seventy-eighth year would not have prevented me from accepting America's generous hospitality, and seeing with my own eyes the enormous progress which the indomitable energy and perseverance of the citizens of the New World have made within the last twenty years.

"Much as I should have felt interested and impressed at their great mechanical and engineering progress, I should have experienced still greater pleasure and pride in visiting their magnificent steel works, and seeing the material that bears my name produced on a scale of greater magnitude than it is in any other country in the world. And when I reflect on the greater honor conferred on me by this application of my labors, I find it difficult to express the gratification it affords me.

"In England, France, and Germany many generous tributes have been accorded me by imperial personages, corporate bodies, and scientific institutions. From the nature of her constitution, America has no knighthood or other title to

bestow. But to a generous people a way may always be found of honoring those whom they desire to honor, and in giving the name of Bessemer to a rising city in the United States they have created a living monument to my memory which will last for centuries after all the titles and medals I have received in Europe have passed away and are forgotten.

"It is in vain I look forward adequately to express my gratitude for this great memorial, but I gladly avail myself of this opportunity of thanking them, though but very feebly, for the honor done me, which far exceeds in generosity and value anything that my invention deserves."

I am quite sure the knowledge that several cities in the United States had been named after him afforded Sir Henry Bessemer greater pleasure and more cause for pride than did all his other successes and recognitions put together. And I wish he could have been able to see the diagrams I have annexed to this monograph, showing the enormous growth of Bessemer steel-making in the United States, and the equally astonishing reduction in cost.

XXVIII.

I think I cannot better conclude this imperfect monograph than by quoting the testimony of three of your great authorities on Sir Henry Bessemer and his work.

Holley, of course, comes first:

"The Bessemer process is remarkable, first, because in all its cardinal features—although not in many details that have given it commercial success—in all its fundamental features it was developed during the brief period of six years, out of nothing, in the way of a kindred and helpful state of the art, by the remarkable man whose name it bears. Within the sixteen years that have elapsed since Bessemer made his first trial, his process has risen from nearly abandoned experiments to the production of a million tons a year. It has indeed progressed, as all successful processes do—whether fast or slowly—by the constant aid of experiment and failure, but the rapidity of its development was due, in a degree not often precedented in the iron business, to the genius of its inventor—especially to that form known as perseverance." *

Next comes Mr. R. W. Hunt, Holley's friend and colleague:

"As I have often expressed it, if we, knowing there was a way through all our troubles, felt so hopeless, what must have been Bessemer's pluck, to enable him to persevere through his difficulties, when the desired end was known only through faith?" †

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* From a lecture delivered before the students of the Stevens Institute of Technology, 1872.

† "The Early History of the Bessemer Process in America," 1876.

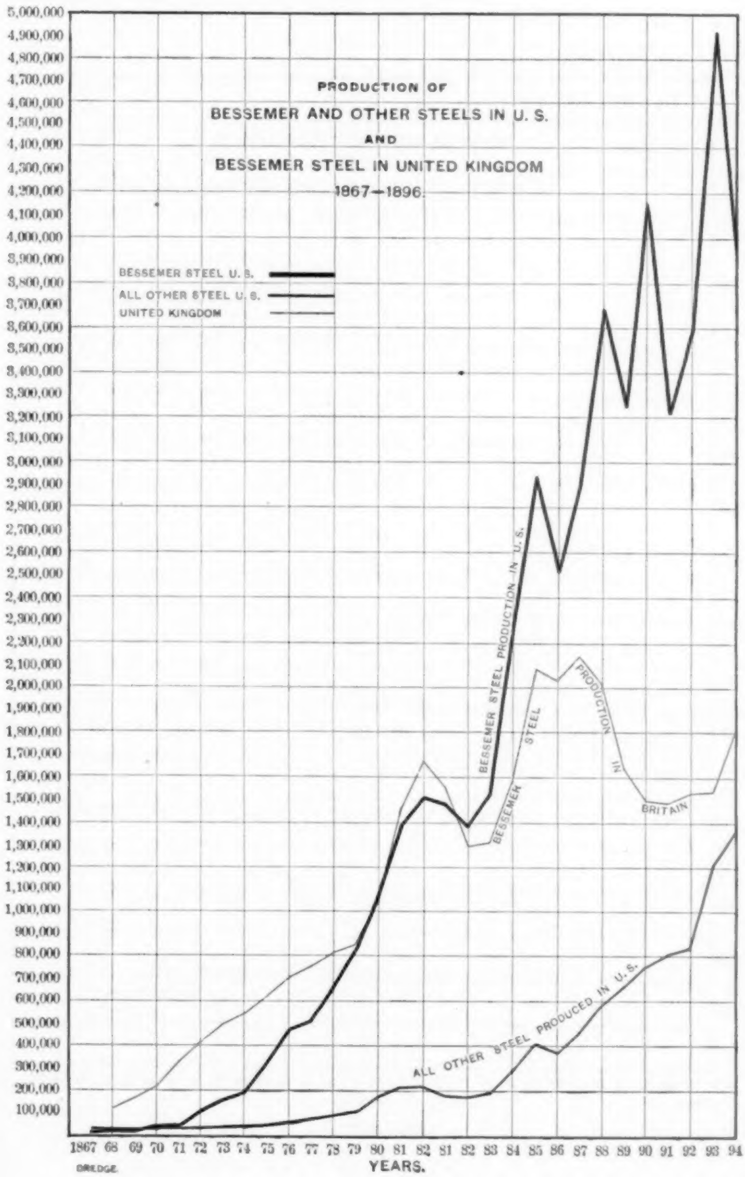
PRODUCTION OF
BESSEMER AND OTHER STEELS IN U. S.
AND
BESSEMER STEEL IN UNITED KINGDOM
1867—1896.
BESSEMER STEEL U. S.
ALL OTHER STEEL U. S.
UNITED KINGDOM
BESSEMER STEEL PRODUCTION IN U. S.
BESSEMER STEEL PRODUCTION IN BRITAIN
ALL OTHER STEEL PRODUCED IN U. S.
YEARS.
DREDGE.

FIG. 206.

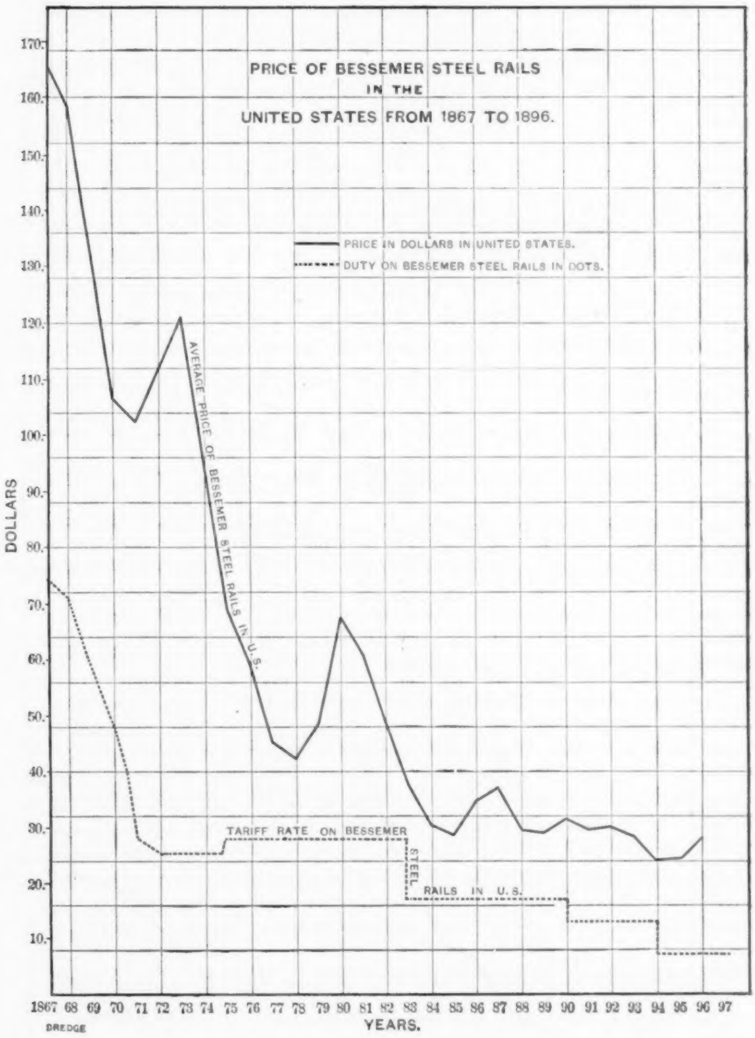
PRICE OF BESSEMER STEEL RAILS
IN THE
UNITED STATES FROM 1867 TO 1896.
PRICE IN DOLLARS IN UNITED STATES.
DUTY ON BESSEMER STEEL RAILS IN DOTS.
AVERAGE PRICE OF BESSEMER STEEL RAILS IN U.S.
TARIFF RATE ON BESSEMER STEEL RAILS IN U.S.
DOLLARS
YEARS.
170.
160.
150.
140.
130.
120.
110.
100.
90.
80.
70.
60.
50.
40.
30.
20.
10.
1867 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97
DREDGE

Fig. 207.

Lastly, the Hon. Abram S. Hewitt:

"A very few considerations will serve to show that the Bessemer invention takes its rank with the great events which have changed the face of society since the time of the middle ages. The invention of printing, the construction of the magnetic compass, the discovery of America, and the introduction of the steam engine, are the only capital events in modern history which belong to the same category as the Bessemer process. They are all examples of the law and progress which evolve social and moral results from material discoveries and inventions. It is inconceivable to us how the world ever existed without the appliances of modern civilization, and it is quite certain that if we were deprived of the results of these inventions the greater portion of the human race would perish by starvation, and the remainder would relapse into barbarism. I know it is very high praise to class the invention of Bessemer with these great achievements, but I think a careful survey of the situation will lead us to the conclusion that no one of these has been more potent in preparing the way for the higher civilization which awaits the coming century, than the pneumatic process for the manufacture of steel. . . . The name of Bessemer will therefore be added to the honorable roll of men who have succeeded in spreading the gospel of 'Peace on earth and good will toward men,' which our Divine Master came on earth to teach and encourage." *

In thanking you once again for having invited me to prepare this monograph, I want to point out to you that the United States has done more than any other nation to honor the name of Sir Henry Bessemer. Its production of Bessemer steel is leaving that of the rest of the world, collectively, far behind. It has inscribed the name of Bessemer indelibly upon its maps; and it has been the first to put on record, in the *Transactions* of your distinguished Society, the outlined story of his career.

* Address of the Hon. Abram S. Hewitt to the Iron and Steel Institute, 1890.

APPENDIX.

The following is a complete list of the patents granted to Sir Henry Bessemer, classified according to their subject matter.

I.

Inventions Relating to Printing.

No.	Patent No.	Date.	Subject Matter.
1	7,585	March 8, 1838	Machinery for casting type.

II.

Inventions Relating to Railways.

No.	Patent No.	Date.	Subject Matter.
2	8,777	Jan. 6, 1841	Checking and stopping railway carriages.
6	10,981	Dec. 5, 1845	Atmospheric propulsion.
8	11,352	Aug. 26, 1846	Railway engines and carriages.
31	2,875	Dec. 9, 1853	Construction of railway axles and boxes.
41	1,390	June 18, 1855	Manufacture of railway wheels.
43	2,319	Oct. 17, 1855	Railway bars.
47	2,327	Oct. 17, 1855	Railway wheels.
55	2,585	Nov. 4, 1856	Manufacture of rails and axles.
65	2,747	Dec. 1, 1858	Railway wheels and wheel tires.
66	670	March 16, 1859	Manufacture of crank axles.
75	2,744	Nov. 5, 1863	Manufacture of railway bars.
114	5,171	Oct. 3, 1882	Loading merchandise ; railway rolling stock.
115	305	Jan. 18, 1883	" " " " "

III.

Inventions Relating to the Manufacture of Glass.

No.	Patent No.	Date.	Subject Matter.
3	9,100	Sept. 23, 1841	Manufacture of certain glass.
7	11,317	July 30, 1846	" " " (also for silvering and coating glass.)
9	11,794	July 17, 1847	Manufacture of sheets and plates of glass.
10	12,101	March 22, 1848	" " " "
11	12,450	Jan. 31, 1849	" " " "

IV.

Inventions Relating to the Manufacture of Pigments, Etc.

No.	Patent No.	Date.	Subject Matter.
4	9,775	Jan. 15, 1843	Manufacture of bronze and other metal paints.
5	10,011	Jan. 13, 1844	Pigments or paints, and preparing same.
13	12,611	May 15, 1849	Manufacture of oils, varnishes, pigments, and paints.

V.

Inventions Relating to Textiles.

No.	Patent No.	Date.	Subject Matter.
16	13,188	July 22, 1850	Figuring and ornamenting surfaces, and machinery employed therein.
19	13,819	Nov. 19, 1851	Producing ornamental surfaces on woven fabrics and leather.
26	1,453	June 18, 1853	Manufacture of waterproof fabrics.

VI.

Inventions Relating to the Manufacture of Sugar.

No.	Patent No.	Date.	Subject Matter.
12	12,578	April 17, 1849	Making sugar and extracting saccharine juices from the cane.
17	13,202	July 31, 1850	Manufacture of sugar; treatment of saccharine matter by centrifugal force.
18	13,560	March 20, 1851	Manufacture and refining of sugar; machinery for producing vacuum.
20	13,988	Feb. 21, 1852	Expressing saccharine fluids, and manufacture of sugar.
21	14,239	July 24, 1852	Manufacture of sugar.
22	795	Nov. 19, 1852	Concentrating cane juice.
23	796	Nov. 19, 1852	Manufacture of sugar.
24	797	Nov. 19, 1852	Treatment of washed sugar.
25	799	Nov. 19, 1852	Concentrating saccharine fluids.
27	1,687	July 15, 1853	Refining sugar.
28	1,689	July 15, 1853	Manufacture of saccharine fluids.
29	1,691	July 15, 1853	Manufacture of sugar.
30	2,811	Dec. 2, 1853	" "

VII.

Inventions Relating to Artillery.

No.	Patent No.	Date.	Subject Matter.
33	1,868	Aug. 25, 1854	Guns for throwing projectiles.
34	2,489	Nov. 24, 1854	Projectiles, and guns for discharging same.
36	67	Jan. 10, 1855	Manufacture of ordnance.
39	1,386	June 18, 1855	" "
41	2,325	Oct. 17, 1855	Ordnance, and projectiles to be used therewith.
68	216	Jan. 26, 1861	Ordnance and projectiles.
70	1,069	April 27, 1869	" " "
77	217	Jan. 25, 1864	Manufacture of projectiles.
78	265	June 30, 1864	Manufacture of armour plates, and machinery therefor.
81	2,343	Aug. 14, 1867	Ordnance.
100	3,230	Nov. 29, 1870	Ordnance, cartridges and projectiles.
101	233	Jan. 27, 1871	Discharging marine artillery.
103	1,466	June 1, 1871	Ordnance and projectiles.

VIII.

Inventions Relating to Metallurgical Processes.

No.	Patent No.	Date.	Subject Matter.
32	1,835	Aug. 21, 1854	Treatment of slag.
35	66	Jan. 10, 1855	Manufacture of iron and steel.
38	1,384	Jan. 18, 1855	Manufacture of cast steel, and mixtures of steel and cast iron.
44	2,323	Oct. 17, 1855	Manufacture of cast steel.
48	2,768	Dec. 7, 1855	Manufacture of iron.
49	44	Jan. 4, 1856	Manufacture of iron and steel.
50	356	Feb. 12, 1856	Manufacture of malleable iron and steel.
51	630	March 15, 1856	Manufacture of iron and steel.
53	1,292	May 31, 1856	Manufacture of iron and steel.
54	1,981	Aug. 25, 1856	Manufacture of iron and steel.
56	2,639	Nov. 10, 1856	Manufacture of iron and steel.
57	2,726	Nov. 18, 1856	Manufacture of iron.
58	221	Jan. 24, 1857	Manufacture of iron.
59	2,432	Sept. 18, 1857	Manufacture of cast steel.
60	2,805	Nov. 5, 1857	Treating iron ores.
61	2,519	Nov. 6, 1857	Manufacture of malleable iron and steel.
62	2,562	Nov. 13, 1857	Smelting iron ores.
63	2,921	Nov. 20, 1857	Manufacture of iron and steel.
67	570	March 1, 1860	Machinery for the manufacture of malleable iron and steel.
69	275	Feb. 1, 1861	Manufacture of malleable iron and steel, and machinery therefor.
71	58	Jan. 8, 1862	Machinery for the manufacture of iron and steel.
73	114	Jan. 13, 1862	Malleable iron and steel ; machinery and apparatus for such manufacture.
76	2,746	Nov. 5, 1863	Manufacture of malleable iron and steel.
79	1,208	May 1, 1865	Manufacture of pig iron.
80	2,835	Nov. 3, 1865	Manufacture of iron and steel, and apparatus therefor.
84	3,714	Dec. 31, 1867	Treatment of cast iron, and manufacture of iron and steel.
85	965	March 21, 1868	Manufacture of refined iron, and malleable iron and steel.
86	967	March 21, 1868	Manufacture of malleable iron and steel.
87	1,095	Nov. 10, 1868	Manufacture of malleable iron and steel.
88	566	Feb. 23, 1869	Machinery and buildings for manufacture of iron and cast steel from pig iron.
89	1,431	May 10, 1869	Manufacture of malleable iron and steel.
90	1,432	May 10, 1869	Manufacture of malleable iron and steel.
91	1,433	May 10, 1869	Conversion of fluid crude iron into fluid malleable iron and steel.
92	1,434	May 10, 1869	Treatment of crude iron.
93	1,435	May 10, 1869	Working blast furnaces.
94	2,379	Aug. 10, 1869	Fusing of metals and alloys, and founding of same.
113	987	March 6, 1880	Purifying iron ; making malleable iron.

IX.

Inventions Relating to Manufactured Iron and Steel.

No.	Patent No.	Date.	Subject Matter.
40	1,388	June 18, 1855	Manufacture of rolls used in the lamination of metals.
45	2,323	Oct. 17, 1855	Metal beams.
52	1,290	May 31, 1856	Shaping and pressing malleable iron and steel.
72	37	Jan. 5, 1863	Apparatus for pressing, shaping, and cutting metallic substances.
111	1,365	April 5	Making iron plate and black plate.
112	4,110	Oct. 10, 1879	Preparing tin plates, bars, and slabs.

X.

Inventions Relating to Navigation.

No.	Patent No.	Date.	Subject Matter.
37	1,352	Jan. 18, 1855	Screw propellers, shafts, and cranks.
42	2,317	Oct. 17, 1855	Manufacture of shafts and cranks.
95	3,707	Dec. 22, 1869	Vessels to prevent sea-sickness.
96	553	Feb. 24, 1870	" " " "
97	1,559	May 27, 1870	" " " "
98	1,580	May 30, 1870	" " " "
99	1,742	June 17, 1870	" " " "
105	2,897	Oct. 1, 1872	Passenger vessels.
106	1,076	March 22, 1873	Controlling suspended saloons.
107	2,274	March, 1894	Ship saloons.
109	4,258	1894	" "

XI.

Miscellaneous Inventions.

No.	Patent No.	Date.	Subject Matter.
14	12,669	June 23, 1849	Machinery for raising water.
15	12,780	Sept. 20, 1849	Preparation of fuel ; apparatus for supplying same to furnaces.
64	1,724	July 30, 1856	Treatment of pit coal.
74	1,439	June 9, 1863	Hydrostatic presses.
82	3,193	Nov. 11, 1867	Grindstones, and other forms of artificial stone.
85	3,501	Dec. 9, 1867	Firebrick, crucibles, ornamental bricks, for building purposes.
103	386	Feb. 15, 1871	Repairing and converting vessels.
104	1,737	July 4, 1871	Asphalt pavements.
108	3,318	March, 1874	Supplying water.
110	4,552	Dec. 31, 1875	Reflectors, lenses, etc.

DCCLXXXIX.

MEMORIAL NOTICES OF MEMBERS DECEASED.

[NOTES.—It has been thought by the Council that the importance of the life work and achievements of Sir Henry Bessemer, Honorary Member of the Society, deceased during the year, should receive a fuller reference than the brief note usual in the necrology of the year.

Readers are therefore referred to the monograph prepared by Mr. James Dredge, of London, which will be found as a separate paper at page 882 of the current volume.]

JOHN THOMAS.

John Thomas was born at Yniscedwin, South Wales, September 10, 1829. The family moved, in 1830, to the New World, and after a brief residence in Allentown they moved to Catasauqua, where Mr. Thomas spent his youth, starting as a blacksmith's apprentice at the Crane Iron Works. Later he entered the machine shops and furnaces, and upon the retirement of his father from the superintendency of the Crane Iron Works his son succeeded him. He filled the position with ability and success until 1867, when he resigned it to become General Superintendent of the Thomas Iron Company's works at Hokendauqua. He remained in this position until 1894, building up the facilities of the works and notably increasing the quality of the product. Advancing years and failing health compelled Mr. Thomas to turn over the active management of the works to his son, and since that time he has been mostly engaged superintending his other business in Pennsylvania.

He became a member of the Society in 1883 upon the proposal of Messrs. Eckley B. Coxe, John Fritz, and others. He passed away at his home March 19, 1897, at the age of sixty-seven years.

CHARLES H. PARKER.

Mr. Parker began his professional career in 1860 as designer on textile machinery, shoe machinery, and general work with the firm of J. B. Parker & Co. In 1860 he became Superintendent of Construction with J. R. Robinson, of Boston, concerned with

the introduction of motive-power appliances, and, from 1866 to 1868, and including a residence at the Paris Exposition of 1867, was with the Shaw Hot Air Engine Company, engaged in experimental work.

It has often been noticed that the achievement of the engineer in public works fails to receive its adequate recognition. It is especially so in the case of an engineer like Mr. Parker, who was concerned with an establishment such as was the National Bridge Works of Boston; for during the seven years of his connection with them, from 1868 to 1875, he designed and built important bridges over the Merrimac at Lowell, Haverhill, and Tyngsboro; and over one hundred and fifty other bridges of different spans, made from the designs of others, were carried through the shop and erected by him. Notable in this list is the Quinnipiac, at New Haven, designed by Clemens Hershel; the iron roof of the large train house of the Boston & Providence Depot, the Boston & Lowell Depot, the Museum of Fine Arts, the Boston Post Office and Treasury Building, and the iron work of the Providence City Hall. Besides this, his works included a large number of oil refinery outfits, tankage pipe lines, mill roofs, blast-furnace works, etc. In the latter years of his life he was connected with the Charles River Iron Works, of Cambridgeport, designing, constructing, and erecting mining machinery, hoisting engines, and power plants. He became a member of the Society at the meeting in Boston, in 1885, and died August 31, 1897.

ALBERT L. IDE.

Mr. Ide was born in Wapakoneta, Ohio, March 20, 1841. He came to Illinois in 1843 with his father, L. H. Ide, and lived on a farm near Williamsville, until 1855, when he moved to Springfield. He early showed his mechanical tastes and instincts, and was a neighborhood clock repairer. In 1856 he entered the shop of Campbell & Richardson as an apprentice and remained with them until the first call for troops in the Civil War. His active service ended as Major of the Thirty-second Illinois Infantry, from which he was honorably discharged for disability after a severe fever. After the close of the war he built and equipped and became president of a city railway line in Springfield, and in 1870 started the business of steam-heating, the capitol building being one of his successful achievements. In

1876 he purchased a shop under an agreement to operate it for ten years, which was the nucleus of the greater development of his later life. About 1880 Mr. Ide became interested in the efforts to introduce a commercial system of electric lighting. At that time Menlo Park and Mr. Edison's laboratory were the only places to study, and he had there his attention directed to the difficulty from unsteadiness in the motive power. It was the experience of these years of designing, construction, and superintendency which developed the engine which was identified with his name. Its mechanical features are well known to specialists. The combination of governing mechanism and self-oiling system, perfected about 1886, resulted in the "Ideal" engine, the name being based upon its designer's own.

He became a member of the Society at the New York meeting in 1884, and his death, the result of peritonitis, occurred September 30, 1897, at Chetek, Wis., to which he had gone for health and rest.

CHARLES BENJAMIN BRUSH.

Mr. Brush was born February 15, 1848, in New York City. He was graduated from the New York University as civil engineer; his first professional work being during the years 1867–69, on the Croton Aqueduct. In this last year he commenced an independent practice of his profession, but in 1874 was made Adjunct Professor of Engineering, and in 1888 full Professor and Dean of the School of Engineering. In 1884 the firm of Spielman & Brush, of Hoboken, was created, and he devoted his time largely to public improvement in his city and neighborhood. He had been concerned in water works practice; was engineer for the contractor of the Washington Bridge over the Harlem, associate engineer for the proposed New York and New Jersey Bridge over the Hudson; was for a time engineer of the Hudson River Tunnel, and was concerned with much of sundry work in Hudson and Bergen counties. He also built the Tully Pipe Line Works at Syracuse, and was either chief, consulting, or associate engineer in many companies. He connected himself with the Society in 1892, and his death, June 3, 1897, came, after a period of ill health lasting for ten or twelve years, from kidney and lung troubles. His retirement from active business began in 1894, resulting from a cold contracted in a personal inspection of the big eight-foot sewer of the town of Union.

THOMAS R. MORGAN.

Mr. Morgan was born in Penydarran, Glamorganshire, Wales, March 31, 1834. He passed away suddenly of heart failure at his home in Alliance, Ohio, September 6, 1897.

He began his life work in the coal mines in Wales as a door boy, and afterwards as mine teamster, his father being one of the contractors in his home district. At ten and a half years a serious accident befell him, whereby he lost his left leg. After earnest schooling in the best schools of his vicinity he served his time as machinist in the Penydarran Iron Works, and afterwards in the Dowlais Iron Works, and later having charge of the iron works at Blaenavon, Pontypool. He left an excellent position, in charge of extensive machine shops, to come to America in 1865, arriving on the very day upon which the assassination of President Lincoln took place. He located himself first in the shops of the Lackawanna & Bloomsburg R.R., and later in the works of the Cambria Iron Company. Removing to Pittsburg, he became Superintendent of the Allegheny Shops, the Atlas Works, and the locomotive works of Smith & Porter. After remaining for several years in the management of these works he engaged in business for himself, beginning in 1868. In 1878 he became General Superintendent of the firm of Morgan, Williams & Co., of Alliance, Ohio, which later became the Morgan Engineering Company, of which he was President to the time of his death. When he began, it was less usual to construct massive and powerful machinery in America, and the early reputation of this firm was built upon their success with hammers, shears, and similar work. Mr. Morgan introduced the practice from England of driving travelling cranes with the continuous square shaft.

WILLIAM A. ROGERS.

Professor William A. Rogers was born at Waterford, Connecticut, November 13, 1832, and died at Waterville, Maine, March 1, 1898. His boyhood was spent for the most part in the interior of New York State, in the villages of DeRuyter and Alfred, where he received his preparation for college. In 1853 he entered Brown University, from which he was graduated in 1857. Before graduation he had already begun his career as a teacher in a classical academy, and immediately after taking his first degree he was

appointed tutor in the academy at Alfred, New York, from which he had gone forth a few years previously as an exceptionally successful student. In 1859 he was advanced to the Professorship of Mathematics and Astronomy in Alfred University, an institution under the care of the Seventh Day Baptist denomination, of which Professor Rogers was an ardent member throughout his life. This position he held eleven years, though absent part of this time for several specific purposes. Among these absences one was devoted to a year of study in the Harvard College Observatory; six months were occupied in work as an assistant in the same place; fourteen months were given to service in the navy during the Civil War, and nearly a year was given to the study of mechanics in the Sheffield Scientific School at New Haven.

In 1870 Professor Rogers severed his connection with Alfred University for the purpose of becoming an assistant in the Astronomical Observatory at Harvard, and, in 1875, he was here made Assistant Professor of Astronomy. This position he retained until 1886, when he accepted the chair of Physics and Astronomy at Colby University, Waterville, Maine. Here the last dozen years of his life were spent; but had he lived a month longer he would have resumed his connection with Alfred University, where a new physical laboratory is now in process of erection. The building was planned by him in 1897, and on the occasion of the laying of the corner-stone, June 23, 1897, Professor Rogers delivered the dedicatory address. His resignation had already been offered to the trustees of Colby University, to take effect April 1, 1898.

During the sixty-five years of his busy life the most distinguishing characteristics of Professor Rogers, as a student and teacher of science, were his indomitable perseverance, industry, care, patience, and accuracy. Beginning as a teacher of pure mathematics, he passed naturally into specialization in astronomy and its allied neighbors, mechanics and physics. His delight was minute measurement, with accuracy to the last decimal place that patient industry could render attainable. He sought accuracy not merely for the securing of the best practical results, but because he had a veritable passion for its pursuit. It was as far back as 1880 that at a meeting of a scientific body he gave the outcome of an elaborate comparison between the standard French meter and the imperial yard, the uncertainty being in the value of the digit occupying the place of ten-thousandths of an inch. Another re-

sult almost identical with the first was reported in 1882 at Montreal as the outcome of new measurements, the meter being equivalent to 39.37015 inches under standard conditions. Still another was given a year later at Minneapolis, 39.37027 inches. At Philadelphia, in 1884, he announced a re-examination of his data, with the expression of his conviction that this result was a little too high, but that the true value could not be less than that given at Montreal. At Buffalo, in 1886, 39.37020 inches was given as a new determination. In 1893, as the mean of eleven determinations, he gave 39.370155 inches. This may be taken as a final value. It has been subjected to two or more revisions by him since 1893, but with no appreciable change as the result. All physical measurements are necessarily only approximate.

The scientific papers published by Professor Rogers are about seventy in number. The first, which appeared in 1869, was forty-five pages in length, and related to the determination of geographical latitude from observations in the prime vertical. He was at this time about thirty-seven years of age, and still connected with Alfred Observatory, where the facilities for research were very limited. Under his direction in 1865 Alfred Observatory was built and subsequently equipped. His activity as a scientific worker was much stimulated after his connection with the Harvard Observatory became established. During the sixteen years of his residence in Cambridge he published forty scientific papers, most of which related to practical astronomy, such as the determination of star places, the calculations of ephemerides, the study of the errors of instruments, the construction of star catalogues from all known data, etc. Included in such work as this the study of the microscope as an instrument of precision was naturally developed, and the methods of securing accurate rulings for micrometers became a subject for the application of industry. This led Professor Rogers into the study of physical standards of length and the construction of ruling machines, regarding which he made himself a generally recognized authority. The articles on "Measuring Machines" and "Ruling Machines" in the new edition of Johnson's Cyclopedia were written by him.

In all accurate measurements of length the recognition of the temperature at which they are made is a matter of prime importance, since a slight variation in temperature produces a measurable change of length. The recognition of this fact caused Professor Rogers to enter into an extended study of the limits of

precision in thermometry, of radiation, and of coefficients of expansion. This continued to be his chief study during the closing years of his life. Nevertheless he kept numerous data from his work at Harvard, and published a number of astronomical papers after his removal to Colby University. His special interest, however, had been gradually transferred to the domain of Physics. In the construction of micrometers he early experienced trouble on account of the scarcity of suitable spider webs, and this caused him to undertake the etching of fine lines on glass. So successful was he in this that a large number of his plates were secured by the representatives of the national government and sent out for use by the observers on the occasion of the transit of Venus. During his study of standards of length he visited Europe, obtained authorized copies of the English and French standards, and brought these home with him. They were then used by him as the bases of comparison for bars which he constructed and ruled, and these are now the chief standards in a number of the most important laboratories in America.

Immediately after his removal to Colby University Professor Rogers undertook the study of thirty mercurial thermometers of the U. S. Signal Service pattern, and, by comparison with these, he secured a standard for the measurement of very low temperatures. It was about this time that Michelson and Morley developed the interferential comparator, and began their investigation regarding the use of the wave-length of sodium as a standard of length. Professor Rogers had already done much work with comparators, and he soon became associated with Professor Morley in the application of optical methods to the determination of minute changes of length. After proper adjustment of apparatus the measurement of almost infinitesimal expansion or contraction becomes possible by merely counting the number of interference fringes of monochromatic light which pass across the field of view in a given period of time. In this way Professor Rogers determined the coefficient of linear expansion of Jessop steel with a degree of precision never before attained. His work in this connection was presented at the Springfield meeting of the Scientific Association in 1895.

In his address last summer at the laying of the corner-stone of the new physical laboratory of Alfred University, Professor Rogers gave a summary of the kind of work which he proposed to undertake personally and with the coöperation of his more

advanced students. Prominent among the subjects had in view were the study of the law of expansion of metals under changes of temperature, the standardization of measures of length, the separate measurement of the effects of hot air and of the heat conveyed by radiation, the energy of heat radiations as determined with the interferometer, the development of the construction of precision screws, the practical development of methods of precision in work-shop operation, the investigation of the relative cost and efficiency of small sources of power, of the economy of various methods for generation of X-rays. This is an excellent summary of the work to which he had been devoting his energies for some years past.

In acknowledgment of his scientific work Professor Rogers was elected, in 1873, to membership in the American Academy of Arts and Sciences at Boston. In 1880 he received the honorary degree of A.M. from Yale, and during the following year he was made an Honorary Fellow of the Royal Microscopical Society. In 1886 he received the honorary degree of PH.D. from Alfred University, on the occasion of the semi-centennial of this institution, and in 1892 Brown University conferred the degree of LL.D. In 1895 he was elected to membership in the National Academy of Sciences. In addition to these recognitions of merit he was made Vice-President of the American Microscopical Society in 1884 and President in 1887; Vice-President for Section A of the Scientific Association in 1882 and 1883, and Vice-President of Section B in 1894. The subject of his vice-presidential address in 1883 was "The German Survey of the Northern Heavens"; in 1894 it was "Obscure Heat as an Agent in Producing Expansion of Metals under Air Contact."

Professor Rogers connected himself with the Society in 1884, after the completion of the joint work done by himself and Mr. Geo. M. Bond, which resulted in the Rogers-Bond comparator, at Hartford, concerning which an expert committee of the Society made its report, published at page 21 of Volume IV., 1883. He contributed also upon his effort to solve the perfect screw problem, and the use of the microscope in the machine shop.

JOSEPH C. G. COTTIER.

Mr. Cottier was born May 29, 1874, at Jersey City, N. J. After an early school education in his native town and preparation in France he entered the Stevens Institute, from which he was

graduated in 1894 with the degree of mechanical engineer. He distinguished himself as a student in the field of mechanics. After graduation he entered business, but found nowhere the opportunities for mathematical study which were his ambition. Accordingly, in the autumn of 1895 he became a university scholar in pure science at Columbia University, in the field of mechanics and mathematics, taking the degree of Master of Arts in '96. He was nearly ready to take his Ph.D. and had been reappointed as Fellow in the Department of Mechanics when his work was cut off by his untimely death in Paris, August 17, 1897, from typhoid fever. Two important papers of Mr. Cottier's may be mentioned. One is entitled "The Application of the Equations of Hydromechanics to the Terrestrial Atmosphere," and the other is entitled "The Application of Curvilinear Coordinates to the Equations of Hydromechanics."

He was travelling in Europe with a companion upon a bicycle tour through the North of France, when both were overtaken by the fever, under which both lost their lives. He connected himself with the Society as a Junior Member, at the Detroit meeting in June, 1895, at which time he was serving as draftsman with the East River Gas Company.

NORMAN RUTHERFORD WEAVER.

Norman Rutherford Weaver was born on a Southern plantation in Dallas County, Ala., March 11, 1869. His parents moved to Salem, Ala., when he was still an infant, and it was there that the child foreshadowed the man, as this young boy turned of his own volition towards mechanics. He set up a telegraphic connection with a school friend, and at twelve years had mastered simple telegraphy, while he eagerly delved into all books of mechanical science which fell within his reach. When at college at Auburn, Ala., he made a small steam engine that for several years afterwards was exhibited to visitors. At this early age he set his mind on inventions, one of which he treasured always and intended by perfecting it to revolutionize steam engineering of modern times. At Auburn he received a diploma and he afterwards studied at Cornell. Seeing no opening for his chosen profession in his native town, he apprenticed himself to the Thomson-Houston Co. at Lynn, Mass., and early became one of their most trusted employees. He developed a faculty for speedily re-

habilitating run-down plants to the eminent satisfaction of owners. It was in this capacity that he went to Galveston, where he was General Manager of the Electric Street R. R. Roanoke, Va., Chambersburg, Pa., Winnipeg, Manitoba, Montgomery, Ala., and Columbia, Tenn., were also scenes of his labors. While at Chicago this young fellow, just in his twenties, was Superintendent of General Electric Co.'s shops, Western Division. He had been known to work forty-eight hours without rest, in order to overcome some difficulty in a previously ill-managed electric plant, and it was such unremitting labor and conscientious giving of his time to business that soon began to prey upon his health. This devotion to his profession would not permit the halt advised four years ago by his family physician, though he might well have complied, as he was a man of means and the son of a wealthy father. As it was, he had planned electric work in Chicago for the year '98, but came home ill in August, '97. After a futile visit to Stafford Spring, Ala., he returned to Selma, dragged out a month or more of suffering and fading hope; then, surrounded by the loving care of relatives and friends, he passed away of Bright's disease, Tuesday, October 5, 1897.

Mr. Weaver joined the Society at the New York meeting, December, 1895.

EDGAR HUBBARD BOOTH.

Edgar Hubbard Booth was born at Marysville, Cal., November 22, 1861. After being prepared at the San Francisco High School for the University of California, he left that institution in 1879 to become an apprentice at the Union Works, at which he remained as machinist and draftsman until 1883. He was designing and superintending engineer at the Union Iron Works, Fulton Iron Works, and the Marysville Foundry and Machine Works, until 1891, when he became Mechanical Engineer with the General Electric Company of New York. His attention had been directed specially to the problems connected with gold and silver milling and mining plants, and in designing and installing electric haulage and pumping plants. His relations as Assistant General Manager of the mining department of the General Electric Company brought him into responsible charge of African installation in 1895 with the Gold Fields Co., Ltd., of Johannesburg, the largest gold-mining plant in the world; notably among these a 1,000-horse-

power electric mining and pumping plant for the Robinson Deep Mine, and a 3,000-horse-power plant for the Simmer and Jack Mine.

He connected himself with the Society in June, 1894, at the Montreal meeting, and died October 24, 1897.

GUSTAVE JACQUES MAILLEFERT.

Gustave Jacques Maillefert was born at Royamont, France, February 3, 1823, and died at New Haven, Conn., December 9, 1897.

Mr. Maillefert was educated in the technical schools of Paris, and, after serving an apprenticeship in a machine shop in that city, was connected with different manufacturing concerns until 1851, when he came to the United States to assist his brother, who was at that time engaged by the Government in an attempt to blast a channel through Hell Gate. Later he was engaged in erecting a government lighthouse at New Haven. Upon the completion of this work in 1853 he entered the service of the New York, New Haven and Hartford Railroad Company at their New Haven shops. He served in various capacities in these shops; at one time having been Superintendent of Erection. At the time of his death he was located in the drafting room. He became a member of the A. S. M. E. in 1887.

In 1861 Mr. Maillefert enlisted in the Second Company, Governor's Foot Guards of Connecticut, with the expectation of seeing active service in the Civil War, but the services of this company were deemed more necessary at home. He retained his membership in the organization for many years.

BURR KELLOGG FIELD.

Burr Kellogg Field was born at Auburn, Indiana, on the 5th day of May, 1856. Soon after his parents moved to Malden-on-the-Hudson in New York State. He prepared for college at the St. John's Military School at Sing Sing, N. Y., and entered the Sheffield Scientific School of Yale University in the fall of 1874, graduating with the class of 1877.

He commenced his engineering career, after graduating from the course of Civil Engineering at Yale University, as a water-boy to a section gang on the Baltimore and Ohio Railroad at the

munificent salary of three dollars per week. Every engineer knows the struggle for existence of young engineering graduates during the period of 1877, 1878, and 1879, and Mr. Field's case was no different except that circumstances forced him to provide for the support of his aged father and mother and younger brother and sister out of his scant earnings.

In July, 1878, he entered the service of the St. Louis & San Francisco Railroad, in the Department of Tracks, Bridges, and Buildings, where he remained until September 10, when he entered the employ of the Denver & Rio Grande Railroad as a rodman on the New Mexico and Colorado Division. After leaving the Denver & Rio Grande Railroad he was engaged as a rodman on the construction of the Omaha extension of the old North Missouri Railroad until August, 1879, when he was appointed as a rodman on the Wichita extension of the St. Louis & San Francisco Railroad, in which place he remained until the spring of 1880, occupying, successively, the positions of rodman, leveler and topographer.

In the spring of 1880, Mr. J. F. Hinckley, now Chief Engineer of the Indianoma Construction Company, was detailed by the St. Louis & San Francisco Railway Company to make surveys from what is now Monett, Mo., to Van Buren, Ark., and Mr. Field was engaged by him as topographer, remaining with Mr. Hinckley until the completion of the preliminary surveys. Much of the country traversed was wild and broken in the extreme, and little or nothing was known about it previous to these surveys. Mr. Field continued as topographer on location under Mr. A. P. Mann, principal Assistant Engineer, and, later, under Mr. M. N. Randall, Locating Engineer. The work covered the territory between Fayetteville, Ark., and Van Buren, Ark., the line crossing the Boston Mountains near where is now located the present station of Winslow. Later Mr. Field was placed as engineer in charge of masonry, trestles, and bridging on the line between Winslow and Van Buren. The masonry and bridging on this portion of the line are important in character, the streams crossed being rapid torrents and the foundations being difficult to sink. Under his direction there were constructed three iron trestles, ranging from 400 to 700 feet in length and from 100 to 120 feet in height, besides some twenty spans of Howe truss bridges resting on masonry piers. Upon the completion of this work, in the summer of 1881, Mr. Field joined one of the surveying parties under the charge of

Mr. R. L. Van Sandt, to complete the location between Van Buren and Fort Smith and to make preliminary surveys through the country from Fort Smith to Paris, Tex. He remained in this position until February, 1882, when he was appointed Assistant Engineer on the Northern Pacific Railroad.

From February, 1882, to November, 1883, Mr. Field was Assistant Engineer on the Northern Pacific Railroad, part of the time in charge of the construction of the Yellowstone Division, and later in charge of the tracks and bridges in the construction of the fifty-two miles of the National Park Branch, connecting the Yellowstone Park with the Northern Pacific.

On January 17, 1884, he was appointed by Mr. John D. Estabrook, then Chief Highway Commissioner of the city of Philadelphia, to the important position of Superintendent of Bridges in the Highway Department of the city of Philadelphia. Two years later, in 1886, Mr. Field accepted an appointment as Assistant Engineer of the Berlin Iron Bridge Company, of East Berlin, Conn. His advancement with the Berlin Iron Bridge Company was very rapid, and at the time of his death, January 13, 1898, he occupied the important position of Vice-President of the company.

WILLIAM ELLISON STEARNS.

Mr. Stearns was born in Newark, N. J., March 2, 1857. During the seven years from 1883 to 1890 he was with the Missouri Valley Bridge Works at Leavenworth, Kansas, and from 1890 to 1892 made his home in St. Louis as Western Agent for the Berlin Iron Bridge Company. From 1892 to 1895 he represented this same company as its Civil and Mechanical Engineer in Connecticut and at Philadelphia. It was during this time that he connected himself with the Society at its Montreal meeting, 1894, connecting himself in January, 1895, with the Maryland Steel Company. In 1896 his health began to fail, and after many months of sojourn in the South, with great advantage, an attack of pneumonia in January, 1898, so prostrated him that he was unable to recover. He passed away May 6, 1898.

CHARLES E. EMERY.

Charles Edward Emery, Ph.D., was born at Aurora, N. Y., March 28, 1838, and died June 1, 1898. He was educated at the Canandaigua Academy and studied mechanical engineering at the

shops of the various manufactories and railroads in the vicinity. In 1858 he started patent soliciting and later in the year studied law, with a view to becoming a patent lawyer, but in 1861 abandoned his studies and entered the Navy as Assistant Engineer. He served throughout the war, obtaining promotion. He was ordered to New York to assist in conducting United States experiments, where he served until 1869, when he retired, and opened an office as consulting engineer and patent expert. In the same year he was appointed Consulting Engineer and Chairman of the Board of Examiners of the United States Coast Survey and Revenue Marine. In this capacity, as a member of a joint board of engineers representing the Treasury Department, Charles H. Loring representing the Navy, he conducted an extended series of experiments to determine the relative value of compound and non-compound engines, the reports of which were extensively published in scientific literature in this country and abroad and were the only reliable data extant. During these tests he was also conducting a series of experiments on stationary engines, and prepared an elaborate circular, subsequently published by W. P. Trowbridge, entitled "Condensing and Non-Condensing Engines." Mr. Emery very soon thereafter received the honorary degree of Doctor of Philosophy, and became the Superintendent of the American Institute Fair.

In 1876 Dr. Emery was appointed one of the judges of the Centennial Exhibition, at Philadelphia, on Engines, Pumps, and Mechanical Appliances, and associate to Committee on Musical Instruments, Electrical, and other Scientific Apparatus.

In 1879 the New York Steam Company appointed him chief engineer and manager, and under his direction the plants of the company, involving an expenditure of over $2,000,000, were constructed and successfully operated. He resigned in 1887.

During this period he conducted many private investigations relating to the isochronism of timepieces, and became an authority on such matters. He made many successful experiments in electricity and built several dynamos and motors that operated by direct current without the use of a commutator. He also became consulting engineer for the city of Fall River, and, upon his report, a novel compromise was effected between the city and the mills whereby the mills agreed to furnish water to the city in consideration of the abatement of taxes on water power. He was also retained as consulting engineer on terminal facilities of the New York and Brooklyn Bridge, and became non-resident

Professor of Cornell University, where he lectured until the time of his death.

In 1888 Dr. Emery was awarded the Watt Medal and Tilford Premium by the British Institution of Civil Engineers, for an approved paper.

In 1891 he resigned from the U. S. Coast Survey and Revenue Marine, as the same had passed into the Navy Department. While in this service he had designed and superintended the construction of the engines of twenty new vessels, and had improved the engines of many others.

In 1893 Dr. Emery was appointed one of the judges of the World's Fair at Chicago, on dynamos and motors, and from that time on devoted himself more particularly to electricity and to water condemnation cases.

He was a member of the commission on the purchase of the Long Island Water Supply Company by the city of Brooklyn, the water supply of the city of Newark against the Mills, the water supply of the city of Skaneateles against the Mills, the city of Lowell water supply cases, and, at the time of his death, represented the Jersey Central in the matter of the Bound Brook floods, the city of Worcester water supply, and the city of Holyoke water-power tax cases.

He has been expert in innumerable patent cases and in suits arising from damage done by defective apparatus. He has also lectured extensively throughout the country before educational institutions; has contributed largely to scientific literature, and is well known throughout the scientific world.

He has taken out many and valuable patents in all branches of engineering, and, in all, has sought to simplify existing mechanism and to render mechanical many of the delicate operations performed by hand.

Dr. Emery was a charter member of the American Society of Mechanical Engineers, of the Society of Civil Engineers, Institute of Mining Engineers, Institute of Electrical Engineers, American Association for the Advancement of Science, and the British Institute of Civil Engineers. He was recently elected a Fellow of the Brooklyn Institute.

EDWIN HOWARD BENNETT.

Mr. Bennett was born in Morrisania, N. Y., April 16, 1845. After the ordinary common-school education he entered the em-

ploy of the Atlantic Dock Steam Engine Works of South Brooklyn, in 1861. In 1861 he entered the Singer Mfg. Works as assistant to his father, Thomas Bennett, and after ten years of increasing responsibilities became Chief Engineer in 1873, and Assistant Superintendent in 1883. Later he was elected a Director, and finally the Treasurer of that company. Since 1879, in addition to his duties with the Singer Company, he was personally concerned with the construction of the details of the Babcock & Wilcox water-tube boilers, and at the time of his death was President of the company. He was also one of the incorporators of the Diehl Mfg. Co. He connected himself with the Society at the Cleveland meeting in 1883, but as the result of his excessive assiduity in business matters he was compelled to lay aside the active duties of his profession in 1896, and failed gradually until his death, June 27, 1898.

WILLIAM HARVEY INSLEE.

Mr. Inslee was born in Newark, N. J., October 6, 1841. After the usual common-school preparation he became apprenticed with the firm of Parker, Snow, Brooks & Co. at Meriden, Conn., and later became machinist with the Hewes & Phillips Iron Works of Newark, serving them as foreman one year and as draftsman for seven years.

In 1869 very flattering proposals were made to Mr. Inslee by the Singer Mfg. Company to take charge of the Adjusting Department, and in connection with this work many improved designs of special tools were originated by him, and the department brought up to a standard of perfection not realizable hitherto. In 1890 he was sent to Scotland by his firm to devise ways and means to bring up the Scotch establishment to the standard which had been secured at Elizabethport, and by his careful and correct work the detail was so systematized that it became possible for Mr. Inslee to be entrusted with larger responsibilities.

He was therefore made Superintendent and General Manager of the Kilbowie Works and made his home in Glasgow, Scotland, until his death, July 24, 1898, in that city. He was unable to rally from a relapse following an attack of appendicitis.

Mr. Inslee joined the Society at its Atlantic City meeting in May, 1895. Among his inventions are the Singer single-thread machine and the peculiar shuttle in the Singer V. S. machine.

There were also many others which were in his mind at the time of his removal to Scotland, which were never completed by reason of the change in his work which followed this change of home.

JOEL SHARP.

Mr. Sharp was born in Mahoning County, Ohio, February 22, 1820. His father had emigrated from New Jersey in 1806.

During his early boyhood, beginning at seven years of age, he earned his living by working on his uncle's farm, getting his schooling during the seven and eight winters of this farm life and completing it with one year, at the age of twenty, in the Friend's School at Mount Pleasant, Ohio. He helped his brothers in various mechanical works, millwrighting and the like, and was for a few years at the Cuyahoga Furnace and Engine Works of Cleveland, previous to 1850. During the succeeding twenty years he was the active man of the firm of Sharp, Davis & Bonsall, and acted as its President, until the Buckeye Engine Co. was created with greater facilities to carry on the work of its predecessors. He continued President of the Buckeye Engine Co., and, associated with Mr. J. W. Thompson, they developed the automatic shaft governor and made a creditable showing at the Centennial Exposition of 1876. In 1885 his labors became too severe in connection with the building of a wire-nail factory in his town of Salem, of which he was also President, and although remaining in office he was compelled to resign his duties with the Engine Company. In the last years of his life failing health compelled him to increasing effort to recuperate his strength, but the loss of energy was progressive, and he finally passed away July 28, 1898. He had celebrated the Golden Anniversary of his wedding, four years before. He connected himself with the Society at its New York meeting in 1884.

JOHN J. SCHOENLEBER.

Mr. Schoenleber was born July 11, 1866, at Ransom, Ill. He became apprenticed with the McDonald Engine & Boiler Works at Des Moines, Iowa, in 1885, after serving as Locomotive Foreman on the C. B. & Q. R. R. After graduating from the Iowa State College in 1889, he devoted himself to electrical engineering in connection with the department of railway work at Chicago. He

came to St. Paul in 1893, and shortly afterwards established the Northwest Engineering Company, conducting an increasing business in electrical supplies and construction work. He passed away after a very brief illness, August 4, 1898. His membership in the Society in the Junior grade dates from 1893, at which time he was connected with the Schenectady Electric Works, in the Department of Railway Motors.

JOSEPH C. PLATT.

Mr. Joseph C. Platt was born January 9, 1845, at Fairhaven, Conn. He was educated in the public schools and fitted at Phillips Academy, Andover, Mass., for Rensselaer Polytechnic Institute, entering that institution with the class of 1866, and graduating with his class with the degree of Civil Engineer.

During the years 1867–1868 he was employed in various capacities in iron works at Scranton, Pa., and in 1869 was appointed an assistant engineer on the Morris and Essex Division of the Delaware, Lackawanna and Western RR. During the four years of 1870–1874 he was engaged as constructing engineer and superintendent of blast furnaces for the Franklin Iron Company, and from 1875 to 1889 was president of the Mohawk & Hudson Manufacturing Company, of Waterford, N. Y., retiring in the latter year on account of ill health.

During the last years of Mr. Platt's life he was engaged in the practice of his profession as a consulting engineer. He joined the Society at the New York meeting of 1891, and died at his home in Waterford, N. Y., July 7, 1898.

JOHN C. O'CONNELL.

Mr. O'Connell was born October 12, 1837, at Mobile, Ala., and was educated at a private school, making a special study of architecture. After finishing school he served two years' apprenticeship in the shop of I. Gregg, located in his native city. At the end of his apprenticeship he accepted the position of third assistant engineer on the steamer *Colonel Clay*, remaining in that position for three years, successfully passing an examination for second assistant engineer, and serving as such for four years more, when he was then made first assistant. Shortly after this the Civil War breaking out, he entered the Confederate service as a third

assistant engineer in the navy, serving as same throughout the war. For a time he was acting as assistant engineer of the Confederate ram *Tennessee*, serving as such in the engagement in Mobile Bay. Afterwards he was in charge of the ironclad steamer *Huntsville*. From the close of the war until 1870 Mr. O'Connell was engaged as chief engineer on lake, bay, and river steamers, with some sea service. Mr. O'Connell was proprietor of the Montgomery Compress Company, of Montgomery, Ala., being in active practice up to the time of his death, which occurred July 12, 1898.

He connected himself with the American Society of Mechanical Engineers as a member at the Philadelphia meeting in 1887.